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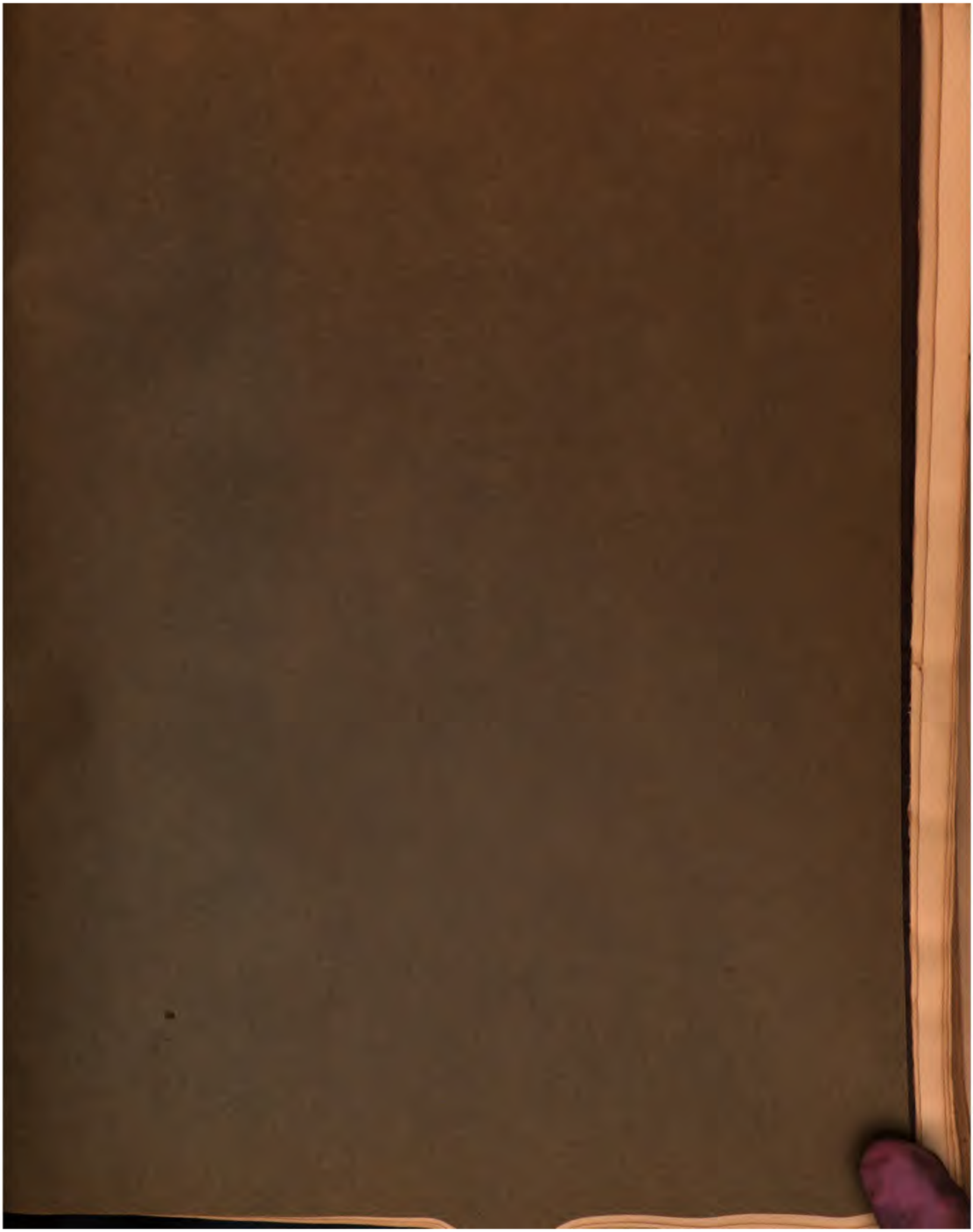

MECHANICAL DRAWING.

PROGRESSIVE EXERCISES

AND

PRACTICAL HINTS.

FOR THE USE OF ALL WHO WISH TO ACQUIRE THE ART, WITH OR WITHOUT THE AID OF AN INSTRUCTOR.

BY

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PREFACE TO PART I.

IT is proper to state that the second part of this book was separately published some time before the first part was written; which accounts for the fact that the chapter on Drawing Instruments is found at the end, and not at the beginning, where it might naturally be looked for.

The exercises contained in Part I embrace the essential features of a course of instruction which has been successfully pursued for twenty years. Those given in the first two chapters are intended not only to train the eye and the hand in the use of instruments, but also to form the habit of exercising forethought, judgment, and taste in relation to the important matter of arrangement.

Reasonable skill in execution having been acquired, the next step is to the delineation of solid objects. And in the treatment of projections the aim is to lead the student to draw these in a matter-of-fact way, as they would appear from different points of view; the express design being to keep out of sight as far as possible the artificial and often useless stage machinery of Descriptive Geometry.

In this manner the beginner is enabled almost at once to construct intelligently simple detail drawings that have a practical meaning and a use, which of itself is a great incentive to further efforts. But this is not the only nor the strongest reason for adopting this course. There are many to whom the representations of tangible and actual things are perfectly clear, while those of abstractions, such as points, lines, or planes, in space, are obscure if not unintelligible; nevertheless they may and often do become expert and valuable practical draughtsmen.

But there are none who will not find a thorough familiarity with the former to be of the greatest advantage in the study of the latter,—one does not study the structure of language before he begins to use it,—and in this subject, as in many others, some knowledge of the concrete is essential to a ready apprehension of the abstract.

C. W. MACCORD.

HOBOKEN, N. J., July 26, 1892.

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MECHANICAL DRAWING.

CHAPTER I.

ELEMENTARY EXERCISES: STRAIGHT LINES AND CIRCLES.

1. **Mechanical** drawing and **geometrical** drawing are by some writers used as synonymous terms; in many treatises the subject is opened up by the explanation of various geometrical problems, and the first exercises consist in drawing, according to the explanation, diagrams representing their solution—thus combining elementary instruction in the science of geometry with that in the art of drawing.

No doubt a knowledge of that science is essential to proficiency in the art; but it is not clear that to study both at once is the best way to acquire either. Those to whom the following pages are addressed, then, are presumed to have gained from other sources an acquaintance with such geometrical principles as may be made use of in the course of the work.

2. A single illustration will serve to show that a distinction may justly be made between the terms above specified.

Let it be required in Fig. 1 to draw through P a perpendicular to AB.

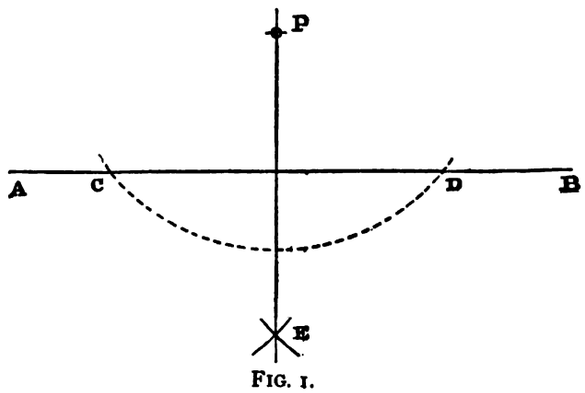


FIG. 1.

The geometrical process is as follows:

1. Describe about P with any assumed radius a circular arc cutting AB in the points C and D.

2. Describe about C and D, with equal radii assumed at pleasure, two other arcs intersecting in E.

3. Draw the straight line PE; it is the perpendicular required.

Now if in the above or any other case, the required result is attained by actually executing the geometrical processes, the operation may properly be called **geometrical** drawing. And it is to be noted that the only instruments admissible are the dividers or compasses, and the ruler or straight-edge. The methods are precise, but the manipulations are often tedious.

3. But by adding a few other simple implements, many operations of constant occurrence in making industrial drawings which involve geometrical principles can be performed with far greater facility, and yet with all the accuracy needed for practical purposes. In illustration may be mentioned the drawing of horizontal and vertical lines by means of the T-square; the use of the scale for bisecting and subdividing lines; and the use of the triangles for drawing lines parallel or perpendicular to others in any position, for inscribing or circumscribing certain polygons, as well as for drawing tangents to circles and finding the points of contact. And that may appropriately be called **mechanical** drawing, in which the use of these and any other labor-saving appliances or devices is permitted. As a matter of fact, they are used in the execution of by far the greater part of the drawings made for constructive purposes.

4. Accepting the latter definition, the following exercises are selected and arranged with a view to imparting facility and accuracy in the use of the instruments. Before proceeding to consider them, it may be well to give a few hints as to the use of the pencil; it is important to begin right, as habits once formed are not easily changed.

1. **Pencil lightly.** Outlines to be inked in should, however, be distinct and firm; centre lines and the like should be finer than these, while "construction lines," etc., which are not to be inked in, should be the finest of all.

2. **Pencil clearly.** Keep the ruling pencils and the instrument leads sharp. Leave in no superfluous or "false" lines; if a line is by any oversight drawn in erroneously, do not leave it to be rubbed out after inking in the rest, but *erase it at once.*

3. **Pencil in only what is to be inked in,** whenever practicable; it is easier to leave out lines, or parts of lines, than to rub them out: and the neatest draughtsman is the one who does the work with the least use of either pencil or rubber. Also, lines which are to be dotted in ink should be dotted in pencilling.

4. Whenever it is possible, mark the extremities of a line by means of the scale, *before drawing the line.* This is often much facilitated by placing the scale against the edge of the T-square; and it enables us to draw the line at once of its exact length, in compliance with the preceding suggestion.

5. In setting off measurements, and in subdividing lines, make use of the scale whenever it can be done, and use the dividers or compasses only when it is unavoidable.

6. Do as much as possible with one setting or adjustment of any instrument, particularly with the dividers or compasses. Much time may be wasted by neglect of this simple precept.

5. In short, the drawing should be made in pencil as nearly as possible as it is to be made in ink. It may take more time to execute the pencilling, but when the habit has been once formed, the difference is less than might be imagined, and is often nearly balanced by the saving of time in the inking in. A chief draughtsman may wish personally to lay out work, which he can, if thus executed, safely leave to be inked in by his assistants; and again, a drawing thus made can upon occasion be traced at once, without being put in ink at all, by which a material saving of time may be effected.

Having mentioned the element of time, it may be well here to add a caution against undue haste, a frequent cause of oversights and errors, which is apt to lead to careless or slovenly work. "*Make haste slowly*" is the golden rule of the draughtsman, whose most valuable qualification is **accuracy**; the next is **neatness**; and the third in importance is **speed**, which is valuable only in so far as it is the result of skill and confidence gained by careful practice, —and worse than worthless if acquired at the expense of reliability.

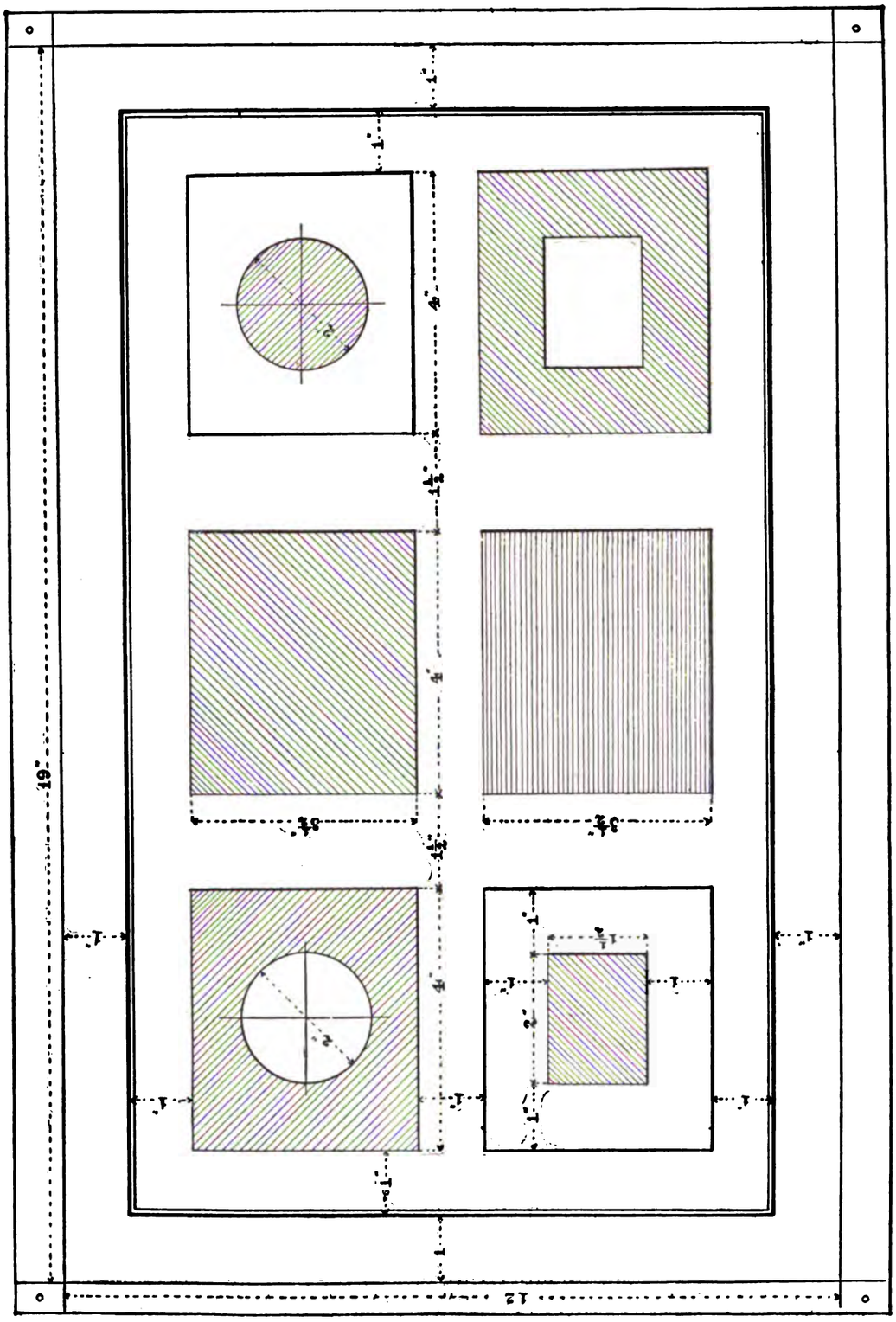
6. It is recommended for the sake of neatness and uniformity that the beginner should make a series of sheets measuring 19 inches by 12, a size requiring a quarter sheet of Double Elephant paper. A margin of one inch all around leaves a rectangle of 17 inches by 10, to be enclosed by a plain or ornamental border. Within this the drawings forming the exercises are to be arranged, with such symmetry as the subjects may admit; and made of such dimensions that they shall neither be so small as to seem lost in the surrounding space, nor so large as to appear crowded.

The effort to accomplish this gives from the outset a training in judgment and forethought which could not be hoped for were exercises of the same nature gone through with regardless of size or of external limitations.

7. The sheet should be placed as near as may be to the lower left-hand corner of the drawing-board, and may be secured by means of four drawing-pins. But, *two* pins will always suffice to keep the paper in place, and one or more must be temporarily removed if they interfere with the T-square or triangles, which should always lie *flat on the paper*. This being arranged, the outer lines may be drawn from edge to edge of the paper, since the sheet when finished is to be cut to the size thus indicated. This final trimming should always be done with *shears;* and never with a knife, the use of which would injure the drawing-board, and sooner or later ruin the T-square, if, as is too likely, it were used as a ruler for this purpose.

8. Fig. 2 represents a completed sheet before trimming; and the exercises which it contains are such that by due attention to the preceding suggestions it is easy to finish up the whole without using the rubber at all. Thus, having set off a point one inch below the upper line, set the T-square against the left side of the drawing-board, and place the scale along its upper edge. Slide the T-square up until the upper edge of the scale passes through the point; then sliding the scale along the square, set off a point one inch inside of each of the outer vertical lines, thus locating the upper corners of the border. Repeating this at the lower side of the sheet, the border can be drawn of its exact size. Again, mark a point one inch below the upper line of the border, and using the T-square and the scale together as before, slide the latter along until its zero point is on the left-hand line of the border, and with the pencil mark the distances 1, 5, $6\frac{1}{2}$, $10\frac{1}{2}$, 12, and 16, *without moving the scale*. These points locate the upper corners of the three rectangular figures drawn in the upper part of the sheet; and it need not be described in detail how in a similar manner all the corners of all the rectangles, as well as the centre lines of the circles drawn in two of them, may be located, so that all the pencil-lines may be drawn without "overrunning" or intersecting.

9. Particular attention is called to the manner of using the scale above mentioned, viz., the setting off *of the sums of successive distances* from a fixed zero. A very common error is to set off the first, then to move the scale, and placing the zero at the point thus marked, to set off the second, and so on. Since there is always a possibility of making an error in


19"
21"
4"
4"
4"
4"
4"
1"
1"
1

setting off any distance whatever, the result of this method is likely to be that the total distance is not exactly equal to the sum of its parts, because the errors may accumulate. In adopting the method recommended, there is at least the security that the total error in laying off any distance within the limit of the scale will not exceed that which may exist in the measurement of one of the parts. This is of greater importance in making working drawings, but a correct method should be used from the very beginning.

10. In regard to "inking in," the following general instructions apply in all cases when the best results are desired:

1. Do not take the pen in hand until the pencil is done with; then ink in all the outlines, of uniform thickness, drawing the circles and circular arcs, if there are any, first, and leaving the straight lines till the last.

2. The centre-lines and construction-lines, if there are any, are to be put in next; and these should be "hair-lines," i.e., the finest of all upon the sheet.

3. When this is done the sheet should be cleaned, and all traces of pencilling removed.

4. The dotted "dimension-lines," if any, should now be put in, and the arrow-heads and figures next.

5. If any parts are shown in section, the "hatching" or "sectioning," by which this is indicated, should be done next.

6. If there be any "line-shading," by which the forms of uncut surfaces are indicated, this should be now executed.

7. The "shadow-lines," which indicate the edges that intercept the light and cast shadows, are put in last of all.

Some terms not yet explained have necessarily been introduced in the above: these will be considered in due course.

11. Thickness of Lines.—Lines are distinguished as fine or coarse, thin or thick, light or heavy, indifferently. The absolute thickness of line which is suitable in any given case cannot be specified by a positive rule, but must be learned by observation and experience. In a general way, however, it may be stated that the smaller the objects represented, and the smaller the scale upon which they are drawn, the finer the lines should be. But it is quite clear that the thickness cannot vary precisely in proportion to the scale, because drawings made on even the smallest scales must be defined by lines which are distinctly visible. Whether thick or thin, however, the lines should be smooth, even, and continuous, and if in ink, perfectly black; as the finish of a mechanical drawing depends very largely upon the quality of the lines.

12. Junction of Lines.—When two lines meet and terminate at the same point, as for example in the corners of the rectangles in Fig. 2, especial care must be taken to make the junction sharp and clean, as shown in the illustrations on the left, in Fig. 3. If through haste or carelessness one or both the lines be made too long or too short, as illustrated on the right, the effect is exceedingly bad, no matter how smooth the lines. Minute defects like this are the first to catch the eye of the expert, while more important errors might escape notice; and they hold the eye, too, like little flaws in a mirror or little cracks in a vase. Indeed, the finish of a drawing depends much upon such small and apparently insignificant things; and besides, it is a fair inference that one who is careless about these points of detail

may be so in regard to greater matters. These remarks apply with equal stringency to the plain "border-line" around Fig. 2, which of itself is, no less than the figures contained

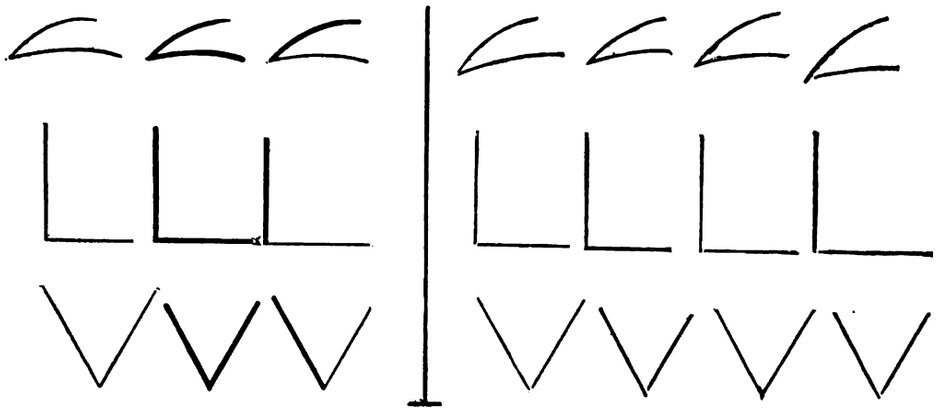


FIG. 3.

within it, an exercise in mechanical drawing; it should be treated with equal deference, and drawn with the same care.

13. Sectioning.—When an object or any portion of it is supposed to be cut by a plane, as in mechanical structures is often necessary in order to show the interior arrangement, the surface of the cutting plane is conventionally indicated by "hatching," to which reference was made in (**10**). This consists merely in covering the surface with fine parallel lines, making ordinarily an angle of 45° with the bounding-lines of the surface when these are straight, and an angle of 45° with the horizontal line when the outlines are curved; which inclinations, however, are subject to modifications in cases to be subsequently discussed. Various parts of the exercise in Fig. 2 are shown as thus "hatched," or, as it is more commonly called, "sectioned," which will serve to give practice in the use of the pen and also of the triangles, meantime training the eye also in judging of equal spaces; for it is to be understood that the distances between the lines are not to be spaced off by any instrument, but determined by the eye alone. The operation consists simply in ruling one line after another, sliding the triangle along the edge of the T-square for the same distance after drawing each one.

14. When a few lines have thus been drawn in succession, an unconscious rhythmic action, as it were, is established, just as one beats time to fast or slow music without thinking, and the manipulation becomes to a great extent mechanical. For this reason a drawing should never be sectioned in pencil first, but this should be done in ink at once: the pencilled sectioning may be excellent, but if inked in afterward, the result is likely to be as bad as if one were to write his name with a pencil and then try to go over the lines with a pen. And for the same reason the sectioning of a drawing should, whenever it is possible, be done at one continuous operation; for if a part be done one day, and another the next, there is likely to be a perceptible difference in the *tone* of the two parts. And again, in making a tracing from a completed drawing no attempt should be made to trace the section-lining: the outlines having been copied, a sheet of white paper is slipped under the tracing-cloth, and the sectioning is done as upon a new drawing.

15. No absolute rule can be laid down as to the width of the spaces between the lines. The general effect to be aimed at is that of a light tint covering the surface; hence it is clear that **the lines of the sectioning should be finer than the outlines.** If a narrow surface be sectioned with wide spaces, the effect will be coarse and unpleasing; *per contra*, the larger the surface, the wider the spaces may be made. If the spaces be too narrow, the effect will be that of a dark tint, tending to crush out the outlines: and besides, it not only requires more time to do the work, but any error in the spacing will be much more conspicuous; and the evenness of the tone evidently depends upon the uniformity of the spaces. It is to be noted also that the section-lines must begin and end at just the right points, neither overrunning nor falling short of the outlines; otherwise the effect is rough and ragged.

16. But the evenness of the tone also depends upon the uniformity of the lines in both tint and thickness. If the ink thickens in the pen, the result is a line either too dark or too thick, or both. The so-called "prepared ink" is peculiarly liable to become viscid in the pen, thus producing this exasperating result; and there is not a bottle of it, of any make, with which it would be safe to undertake the sectioning, much less the line-shading, of any elaborate plan. **Throw the bottle out of the window;** mix up a liberal quantity of good China ink with clear water in a clean saucer, a little thinner than for outlining; test the pen; practise a minute on some scrap of paper until hand and eye act in unison and the proper space is determined; then proceed with confidence and hope of success. In Fig. 2 one of the rectangles is ruled with equidistant horizontal lines, in the manner of line-shading a plane surface. These, too, are to be spaced by the eye, and the above remarks apply to them as well.

17. Shadow-lines.—In Fig. 2 it will be observed that some of the outlines are much heavier than others; and no one can fail to be struck by the effect of *relief* thus produced, nor to appreciate that the figures are not mere diagrams, but represent objects of sensible thickness, which if resting upon a plane surface would cast shadows upon it. The lines which are thus made heavy are technically called **shadow-lines;** and in all cases they represent the sharp **edges** of surfaces, which intercept the light. Thus they not only give the power of producing relief in outline drawings, but afford at once the means of distinguishing an object which has sharp edges, as for instance a prism, from one which has not, such as a sphere or a cylinder. Of course it would be out of place here to attempt the full explanation of how to determine in all cases what lines do cast the shadows. But this must depend to a great extent upon the direction from which the light comes; and for the sake of uniformity it has been agreed that on the drawing this direction shall in all cases appear to make an angle of 45° with the horizontal line, as indicated by the arrow in Fig. 4, it being understood that the rays of light are not *parallel* to the paper, but come from a source above the object as well as to the left of it.

18. Suppose then that in this figure *ABCD* represents a square block lying on the paper, and perforated by a square opening *EFGH*, all the edges being sharp. It will be seen at once that *AB*, *BC*, *EH*, and *HG* are the lines which cast shadows, and they are made heavy accordingly. Let *X* represent a torus, or ring, such as can be made by bending a cylindrical rod around a mandrel: this body would certainly cast a shadow, but it has no edges, and therefore no shadow-lines. Let *Y* represent an annulus, or ring formed by bending a square bar around a mandrel: then the outer and the inner circles represent edges, and portions of

both will cast shadows, falling away from the light. Draw rays of light tangent to the outer circle at *m*, *n*: then, as any one can readily satisfy himself by laying a disk, say a coin, upon the table in the sunlight, the semicircumference *man* will not cast a shadow, while *nbm* will do so; moreover, the shadow will be broadest opposite *b*, the point midway between *m* and

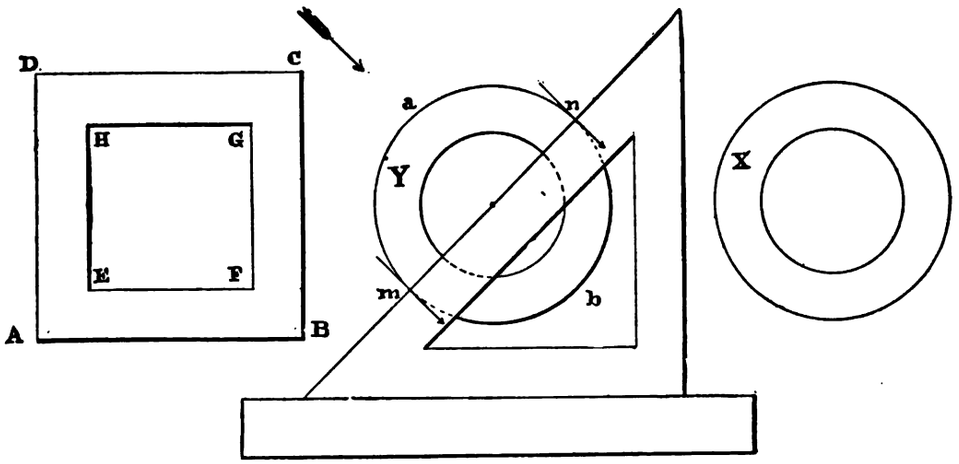


FIG. 4.

n, gradually diminishing in breadth as it approaches these points of tangency, where it will disappear. And, similarly, the opposite half of the inner circumference will cast a shadow, likewise tapering out to nothing at the points of tangency to parallel rays.

19. Of course it is not necessary actually to draw these rays, since, as indicated in the figure, the points of tangency can be at once marked by means of the 45° triangle.

In order to draw this tapering shadow-line the compasses must be put in motion *before the pen touches the paper* at *n*; the pressure is gradually increased as the pen approaches *b*, gradually diminished as it approaches *m*, and the pen is removed from the paper *while still in motion*. The whole action is very similar to that of free-hand flourishing with a writing-pen, and is easily acquired with a little practice.

If the line is to be quite heavy, it may be necessary to go twice or even three times over the broader part. Beginners are very apt to think that the object can be accomplished by slightly shifting the centre—a very dangerous expedient, unless the line is to be made excessively thick, as it might be for a lecture-room diagram; for it is almost impossible to move the needle-point through a distance sufficiently minute without having it slip back again into the hole made by it in the original position. For all ordinary purposes the method above advised is the safest and the best.

20. Border-lines.—The preceding instructions embrace all that is necessary for the completion of the *exercises* given in Fig. 2, and apply equally to all those following which come within their scope. A word may now be said as to the border-line by which they are surrounded. In general such an ornamental adjunct is not appropriate in connection with separate detail drawings; but when a series of sheets of uniform size is to be made, it may be introduced with good effect. Around topographical drawings, however simple and crude, a border of some kind is regarded as almost indispensable. But wherever used, it is in a

sense ornamental and superfluous, it challenges criticism, and should be executed with scrupulous care. Subsequently some examples will be given of more ornate borders with correspondingly elaborate "corner-pieces," suitable for drawings of a pictorial nature; for the present, the less pretentious "plain border," consisting, as shown in Fig. 2, of a fine interior line and a thicker one without, will suffice to exercise the skill of the tyro.

The absolute thickness of the outer line is to a great extent dependent upon individual taste; the standard adopted in topographical work is $\frac{1}{100}$ of the breadth of the map—which would give, for the borders here proposed, enclosing a space 10 inches wide, an outside line $\frac{1}{10}$ of an inch thick: and this should also be the breadth of the white space between the outer and inner lines.

No attempt should be made to make even a line so thick as this at one stroke of the pen, nor yet to cover the whole with ink *at once*, as is sometimes done by means of a brush, or worse yet, by "filling in" the space ruled by two finer lines by the use of either the drawing-pen or a writing-pen. Such a river of ink not only requires a long time to dry, but is apt to cause the paper to "buckle," after which it is very unlikely to become smooth upon drying.

The proper course is this: Rule parallel lines of moderate thickness *a short distance apart;* when these are thoroughly dry, and not before, rule others between them, until the whole breadth is covered. Thus a smooth, black, and even line of any width may be obtained.

21. Converging Lines.—When, as in Fig. 5, a number of lines are to be drawn radiating from a single point, it is clear that one will meet and merge into another at some little distance from the actual point of convergence. In such cases wait until each line is dry before drawing the next one, in order to avoid the accumulation of a mass of ink at the junction. And this will be avoided with the greater certainty by drawing the lines *away from* and not *toward* the point from which they radiate.

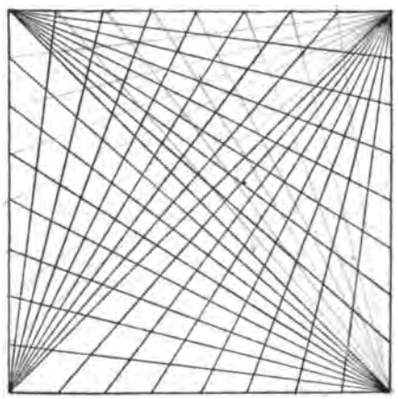


FIG. 5.

22. Fig. 6 is a sheet of exercises similar to those of Fig. 2, and no additional instructions are required, except in relation to the inner corners of the hollow rectangle, which are rounded, or, as it is technically called, "filleted." In pencilling, the sides of the inner rectangle are drawn first, and the circular arcs next drawn tangent to them with the bow-pencil. The centre c of such an arc, Fig. 7, A, can after a little practice be readily and accurately located by trial, after which, if it be deemed necessary, the points of contact, m, n, may be marked by aid of the T-square and triangle. If the radius of the circle is large, it will be advantageous to draw a short line at an angle of 45° through the corner x of the pencilled rectangle, upon which the centre must lie, as in Fig. 7, B; or to set off from x, as shown at E, the points m, n, with the given radius, and around these points to describe short arcs with the same radius, intersecting in the required centre.

But in drawings of machinery so many of these small fillets are met with, that such geometrical operations consume too much time.

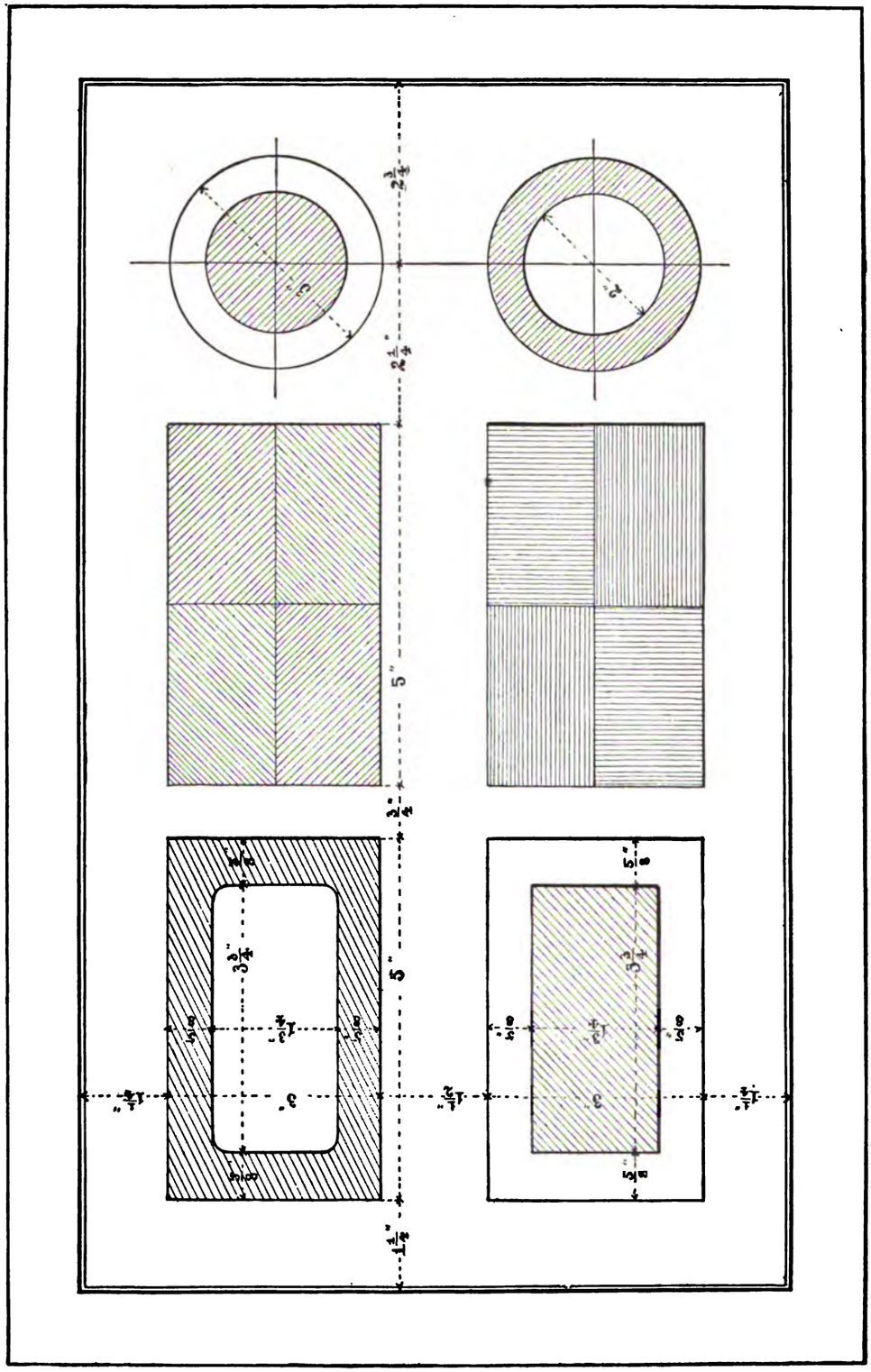


FIG. 6.

23. Ink in the circular arcs first and the right lines last, because it is much easier to join the right line smoothly to an arc already drawn, than to join an arc smoothly to even one right line, let alone two—as may be readily proved by trial. In the case of a circular arc the reason is clear, for the least error in either centre or radius will produce a sensible effect at one or both the junctions. It may be said that such an error would impair the accuracy of the work even if the arc were inked in first; this is true, but if the error be, as it often is, practically unimportant, there is no need to make it conspicuous, as it will be if the junction, as at Fig. 7, *D*, is careless or imperfect.

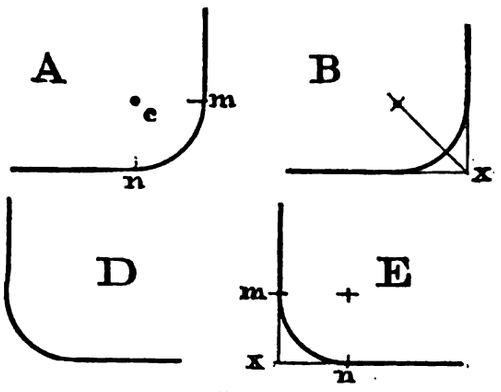


FIG. 7.

The difference in the difficulty of making a continuous line is not so great if the curve be one for which a "sweep," or curved ruler, can be used; but a systematic procedure is likely to save time, and straight-line work is preferably left to the last.

24. Sectioning of Hollow Figures.—In Fig. 8 are shown transverse sections of a hollow rectangular beam and a hollow cylinder. In sectioning these at the angle shown, it is natural and right to begin at *C*. After passing the point *E* many think it necessary to section the

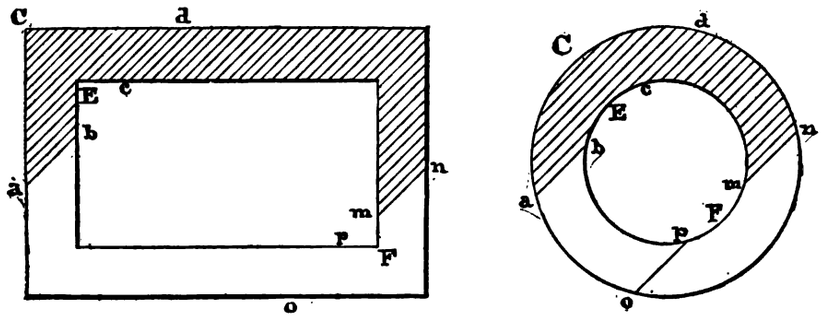


FIG. 8.

opposite sides *at the same time*, drawing, for instance, the line *ab*, then the line *cd*, without moving the triangle. This involves a serious loss of time, if the surfaces are of any considerable magnitude.

A better method is to section the upper side first, going on from *cd* to the right, stopping when a line *mn* is drawn, such that a half-dozen or so more would carry us to the point *F*. Then go back to *ab*, and section the other side—it will then be seen that when the edge of the triangle again coincides with *mn*, the error in the position of *op* cannot exceed half a space; and by dividing this error up among the spaces yet remaining before reaching *F*, the individual variations will be imperceptible. The saving of time in the sectioning of a large cylinder by adopting this method instead of the other amounts to fully twenty-five per cent, after a moderate degree of facility in the manipulation has been attained.

TANGENCY OF CIRCLES AND LINES.

25. For the purpose of acquiring skill in the handling of the compasses, and habits of care in the execution of work at every step as well as in the final processes, no practice is better than that afforded by exercises in which it is required to draw a number of circles within a given figure, tangent to it and to each other; some of which may now be appropriately taken up, in order to relieve the monotony of continuous straight-line work.

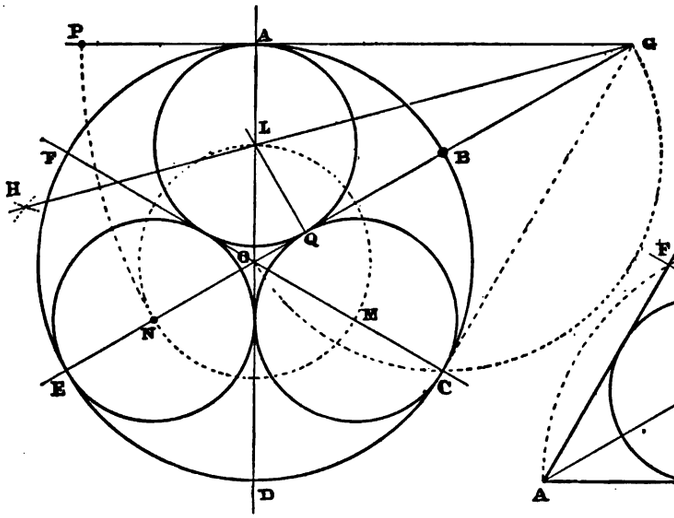


FIG. 9.

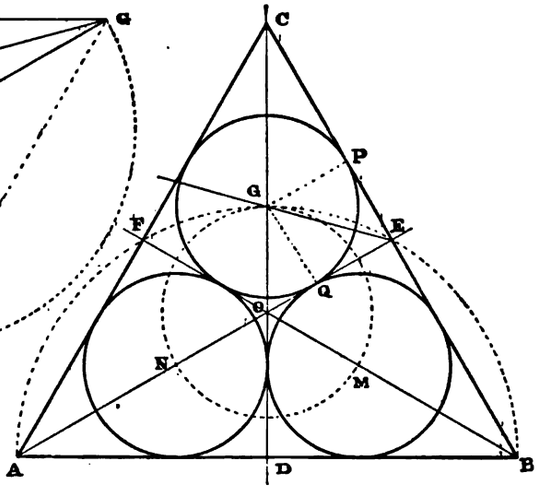


FIG. 10.

Two such exercises are given in Figs. 9 and 10, the external figures being a circle and an equilateral triangle, within each of which three tangent circles are to be inscribed.

26. To construct Fig. 9.

1. Draw the vertical centre line and describe the larger circle about O.
2. *Without laying down the compasses*, set the needle-point at D, and mark the points C, E, the radius being unchanged.
3. Similarly, set the needle-point at A, and mark the points B, F.
4. Still with the same radius, describe about B the semicircle OCG.
5. Draw the diameters FC, EB, and produce the latter to G.
6. Draw the tangent at A, and produce it also to G.
7. Bisect the angle AGO by the right line GH, cutting AD at L.
8. Describe about O a circle through L, cutting CF and EB at M, N.
9. About L, M, N, with radius LA, describe the three required circles.

27. To construct Fig. 10.

1. Draw the vertical centre-line of indefinite length.
2. Lay the scale against the T-square, set off $DB = DA$, and draw AB.
3. Set the zero of the scale at A, and mark the point C on the vertical centre-line, making $AC = AB$.
4. See if CB is equal to AB; and if correct, mark its middle point E.
5. Mark with the scale the middle point F of AC.

6. Draw AE, BF, cutting CD in O, the centre of the triangle.

7. Bisect the angle AEC by a line cutting CD in G.

8. Describe a semicircle on diameter AB: it should pass through G.

9. Describe about O a circle through G, cutting AE, BF, in N and M.

10. Draw GP perpendicular to BC; it is the radius of the required circles.

28. The above instructions have been made thus explicit in order to emphasize one or two points already mentioned; more particularly, the doing as much as possible at once with one adjustment of the compasses, as in Fig. 9, and the use of the scale when practicable instead of the compasses, as in Fig. 10. It is very common to see the triangle laid out by striking arcs about two of its angles as centres: in doing this, holes are pricked in the paper, into which the ink will run, so that the sharp finish desirable is dstroyed. **Use the scale.**

Another object is, to call attention to the advisability of *checking* the accuracy of any step, when the greatest precision is required. Thus in Fig. 9 the point G is the intersection of the tangent at A with the prolongation of the diameter EB; and the precision with which it is located is confirmed if it falls, as it should, upon the circumference OCG: evidently, an error here would be vital, and affect injuriously the final result. Another instance is found in Fig. 10, where the intersection of the two straight lines EG, CD should fall on the semi-circumference AGB. The application of such checks is particularly necessary in laying out diagrams of this description, for though geometrically simple, they are practically very difficult to draw with perfect precision.

29. Bisection of an Angle.—In Fig. 9 the arc NP is drawn, merely to indicate that the arcs intersecting at H, in bisecting the angle AGO, are described about centres P and N, equidistant from the vertex G; and thus in this illustrative diagram to make a record of the processes. Practically, the arc need not be drawn at all, it being sufficient to set off by the scale the two points P and N, and the farther from G the better; for the distance between H and G being thus increased, any error in the direction of the line determined by those points will diminish as the line approaches the vertex. Theoretically, the radius of the arcs intersecting at H is arbitrary; but if they cut each other acutely, it is obviously difficult to locate the precise point of intersection.

Not only in the bisection of angles, then, but in various other operations, the draughtsman should always keep in mind the two following important principles, viz.:

30. 1. Points for locating lines should be as far apart as possible.

2. Lines for locating points should cut each other normally, as nearly as possible.

31. The necessity of exercising great care at every step in constructing these and similar diagrams will be appreciated if we consider for a moment what tangency really means. Supposing the instrument lead to be sharpened, as it should be, to a keen edge, so as to draw a fine clean line, two tangent circles ought to appear as at A, Fig. 11; merging at the point of contact into one line without increased thickness. A very slight error in the radius or the position of the centre of either of the circles will lead to conspicuous faults, shown at B and C. That there should be no increase of thickness at A, is clear from the consideration that the pencil (or ink) marks represent mathematical lines, which have no thickness; so that two, or twenty, are no thicker than one.

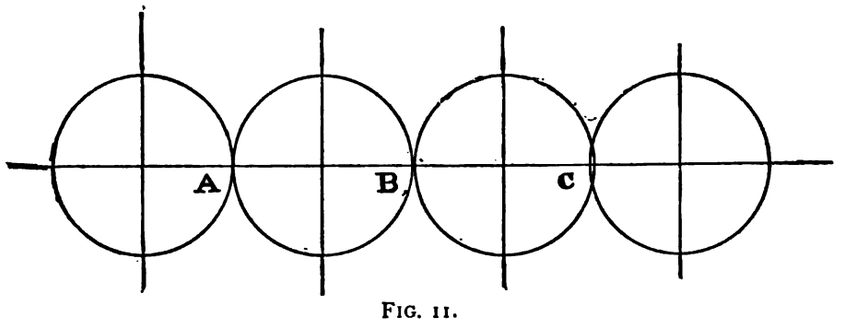


FIG. 11.

32. In inking in, however, a much more effective appearance may be given to such exercises by using lines of different thickness; the centre-lines and construction-lines being very fine, while the given figure and the required tangent-circles are made much thicker. This is entirely distinct from the use of shadow-lines: all the heavy lines here referred to are made of uniform thickness, and perfectly smooth and even. In this way the data and the results, being made bold and prominent, strike the eye at once, thus better exhibiting the nature of the problem; while the processes by which the results are reached, though clearly indicated, take their proper secondary place.

Use of Broad Lines.—It is sometimes necessary to represent a line by a broad band, as for instance in making lecture-room diagrams, which must be distinctly visible to the whole audience. When seen from a sufficient distance, such a band will appear like a fine line, the position of which is mentally referred, not to one or the other edge of the actual stripe, but to its centre. Such diagrams should therefore be drawn at first with at least moderately fine lines, *on each side of which*, at equal distances, parallel lines may be drawn, the space between them being subsequently filled in.

33. It follows from this, that no matter how heavy the lines of the triangle and the circles in Figs. 9 and 10, they will be no thicker at the points of tangency than anywhere else. When viewed from a short distance, the lines no doubt seem to coincide for a sensible extent, instead of at a single point: but so would finer lines if put under a microscope; and if the eye be sufficiently removed, these heavier ones will appear truly tangent, as in fact they are. Beginners are apt to think that two tangent arcs should, when drawn with broad lines, appear as in Fig. 12, *A*, because, as they say, the lines just touch each other. The fallacy will be clear if this method is applied to a reverse curve composed of two tangent

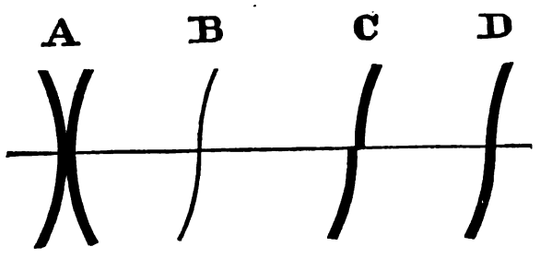


FIG. 12.

arcs, as at *B*; the effect is shown at *C*, one glance at which is enough, it being perfectly obvious that the result desired is that shown at *D*, which is produced as above explained.

34. Dotted Lines.—Some of the lines in Figs. 9 and 10 are what are technically called "dotted;" which strictly means *broken*, that is, formed of alternate short dashes and spaces, for true dots cannot be made with a drawing-pen, nor would they equally well convey the idea of *direction*, if they could be.

In working drawings, dotted lines are used to indicate the outlines of parts concealed by intervening objects; but as to lines used merely in construction, there is no absolute rule for determining which ones should be dotted and which should not. But in all cases the dotting should be regular and even, the spaces just long enough to be distinctly seen, and equal in length to the dashes. If the dashes are long, no matter how regular, the effect is that of apparent haste; and no one minor thing adds so much to the finish of a drawing as dotted lining which is fine, firm, clear, and well spaced.

35. Figs. 13 and 14 are exercises precisely similar in character to those given in Figs. 9 and 10. In Fig. 13 the centres and points of tangency divide the diameter into six equal parts: they may therefore be at once marked at one setting by means of the scale, by selecting a suitable value for *LM*, and making *LR* six times as long.

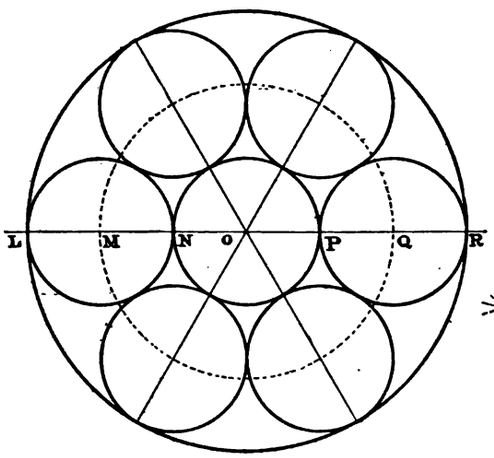


FIG. 13.

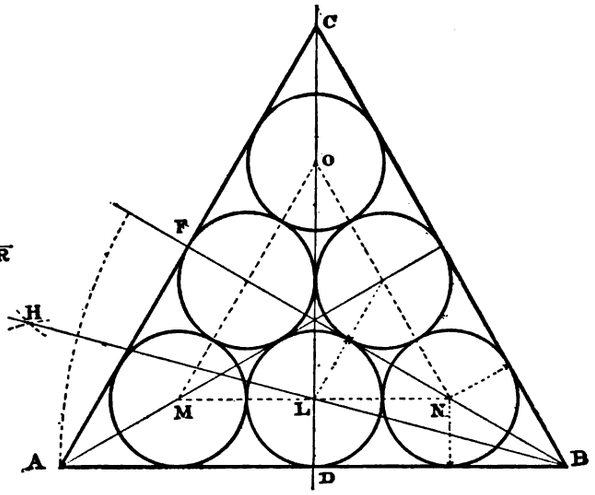


FIG. 14.

In Fig. 14 construct the triangle by means of the scale, as in Fig. 10; bisect the angle *ABF* by the line *BH*, cutting the vertical *CD* in *L*, the centre of one of the required circles; the other centres are determined by drawing the equilateral triangle *MLNO*.

36. Judicious Arrangement of Diagrams and Drawings.—It is understood that, as intimated in (**6**), the border-line is to be first drawn, and the exercises arranged within the space thus enclosed. In order that the sheet when completed may present a neat and well-balanced appearance, due attention must be paid to the relative positions as well as the actual dimensions of the figures which compose it. The two pairs of diagrams mentioned in the preceding section sufficiently illustrate the fact that perfect symmetry is not always attainable;—which is here emphasized, because experience has shown that beginners are very apt to think that when, as in these cases, two figures are to be drawn, the first thing to do is to draw a vertical line through the centre of the paper. Nothing could be more erroneous,

as the reader will at once perceive by imagining a border to be drawn, say, around Figs. 9 and 10. Were the space within the border thus divided into two compartments or panels, the diagrams would have to be made so small as to be out of all proportion to so large a sheet. Should this dividing line be inked in, the effect would be more tolerable; but if not, the two figures would, by reason of the great distance between them, appear as if they repelled each other, and were crowded out toward the border-line.

The fact is, that one diagram is in a sense a border to the other; and even if, as in some of the following examples, they are perfectly symmetrical, it should be kept in mind that the space between the two need not be any greater than that between either of them and the adjacent end line of the border.

37. Fig. 15 is an open-work eight-pointed star enclosed within two interlacing hollow

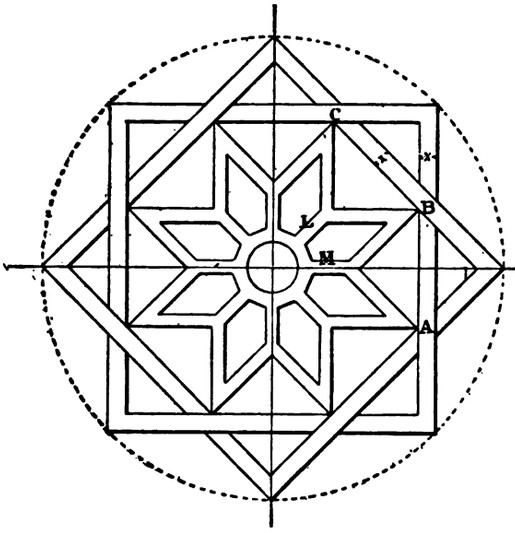


FIG. 15.

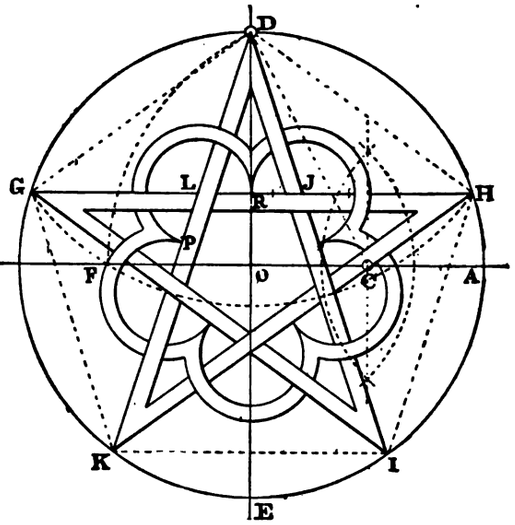


FIG. 16.

squares. The latter are first drawn, and the breadth x evidently determines the positions of the points A, B, C, etc., of the star. The radiating arms L, M, etc., might be laid out by first drawing a centre-line for each, and setting off the half-breadth on each side with the spacing dividers; but a better method is illustrated in Fig. 17. Draw in pencil a small circle at the centre of the star, of a diameter equal to the breadth of the arms, whose outlines are drawn tangent to this circle by means of the T-square and the triangle. The eye can judge with great nicety as to the fact of tangency; and this method will be found of great advantage in many similar cases.

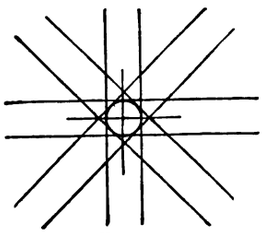


FIG. 17.

38. Fig. 16 is another example of interlaced work, the fundamental figure being a five-pointed star. To locate the points of this star means to inscribe the pentagon in the circle, which is done as follows:

1. Bisect the horizontal radius OA at C.

2. About C describe an arc through D, the extremity of the vertical radius, cutting the horizontal diameter in F. Then $DF =$ side of pentagon.

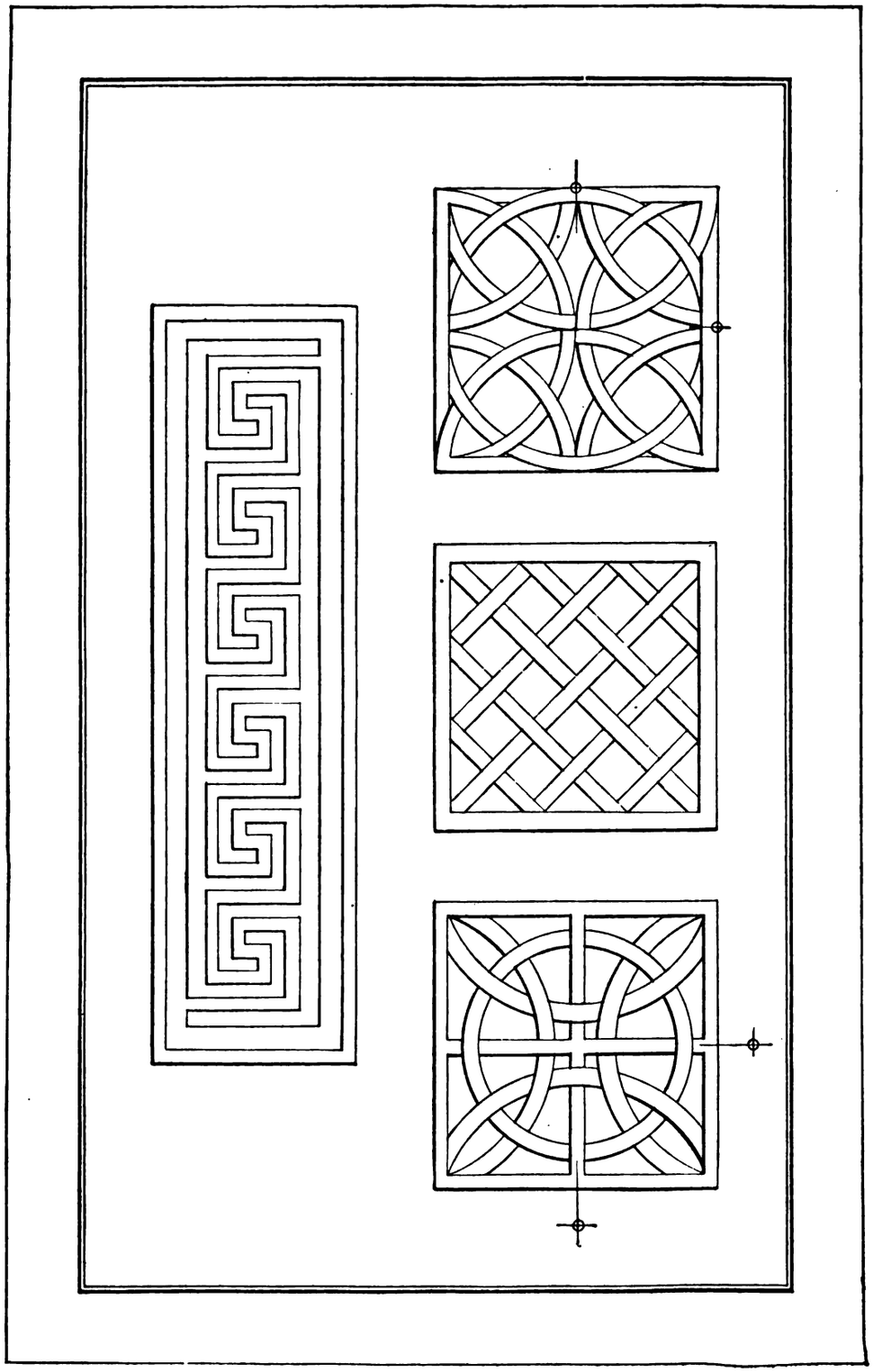


FIG. 18.

The centres of the circular arcs forming the inner interlacing figure are the intersections *J*, *L*, etc., of the outer lines of the star. The radius of all the inside arcs is equal to half *JL*; these arcs are therefore *tangent* to each other at *R*, *P*, etc.; and great care must be taken in manipulating the shadow-lines, in order to produce the *sharp* knife-edge finish essential to a proper effect.

39. In the drawing of interlaced work it is clearly impossible to leave out in pencilling all lines which are not to be inked in, because it cannot be known just which ones they are. Since then all the lines must be pencilled in at first, crossing each other as they may, this should be done very lightly; after which it is advisable, as a precaution against mistakes with the pen, to erase carefully with the sharp corner of a small piece of rubber those portions which are not to be drawn in ink. Work of this description gives good training in the use of the pen, since, in order to avoid a ragged appearance of the drawing, the lines must meet sharply without overrunning; its perfect execution requires both care and skill.

40. Fig. 18 represents a completed sheet, in which the three upper figures are simple exercises in interlaced work; the locations of the centres of the circular arcs being indicated, no explanation is necessary. The lower figure is a panel ornamented with fretwork in the Greek style, the panel being sunken and the fretwork raised; the effect being made pronounced by the use of quite heavy shadow-lines. This pattern, though very simple, is yet of such a nature that the attempt, by using the scale for each member and part of a member, to end *every* line in pencil just where it is to end in ink, would be clearly absurd.

Rule the horizontal lines very lightly from end to end, as indicated by fine lines in Fig. 19;

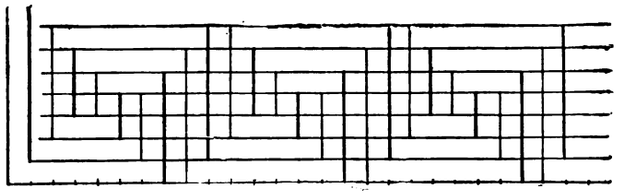


FIG. 19.

lay the scale on the lower line, and with a sharp pencil set off the longitudinal spaces: then by means of the triangle the *vertical* lines can at once be drawn of exactly the right length. After this is done, it will be safer to pencil in a little more strongly, by means of the T-square, those portions of the horizontal lines which are to be drawn in ink; without this precaution mistakes with the pen are likely to occur.

41. Fig. 20 is an exercise which, while apparently simple, is yet a very difficult one to execute perfectly. The diameter of the outer circle being divided into any number of equal parts, begin at one end, and describe a semicircle upon each part, on the same side of the diameter. Then, beginning at the other end, do the like in reverse order on the opposite side of the diameter. Thus at each extremity of the diameter a number of arcs are tangent to each other; in order to prevent blotting, begin with the outer one, and wait until it is dry before drawing the next. This order is also best for another reason—the lines, having some thickness, actually meet each other before reaching the point of tangency; hence the pen need not always start from that point, but may first touch the paper where the lines coalesce.

Moreover, the curvilinear angles become less and less toward the outer part, so that the *daylight* between the arcs should extend farther in toward the point of tangency, as the radii diminish; this requires close attention, and can be better controlled by following the above order in drawing the semicircles.

Instead of assuming at random a radius for the outer circle and using the dividers for subdividing it, thus marring the paper, it is advised to set off an assumed unit the requisite

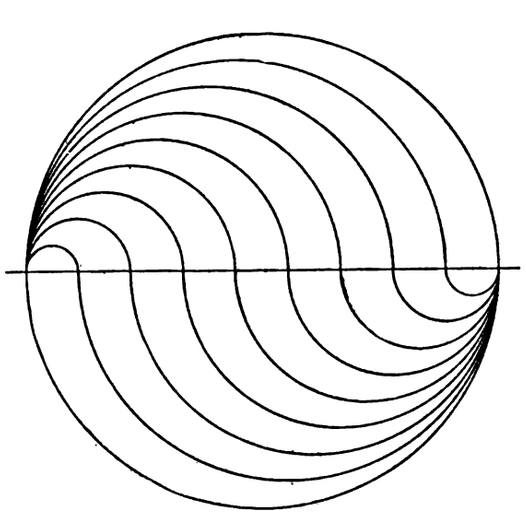


FIG. 20.

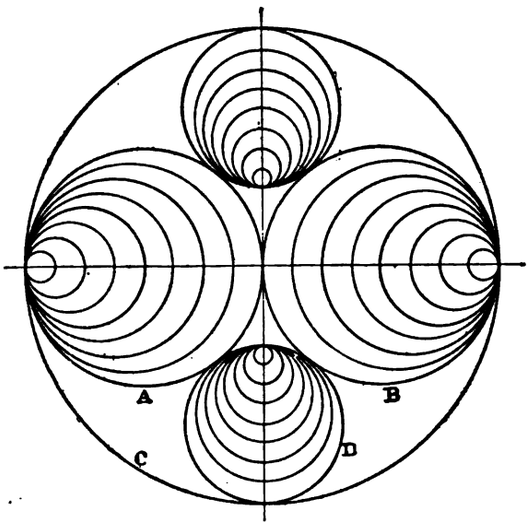


FIG. 21.

number of times by means of the scale and pencil, thus locating at once both the centres and points of contact of the various semicircles.

42. Fig. 21 is an exercise of analogous character, in which the subdivisions on the horizontal diameter may also be most advantageously set off by using a scale, as above explained, the diameter itself of the outer circle C being also thereby determined.

This being done, it is clear that the centre of the circle D, which must be tangent to the three circles A, B, and C, must lie on the vertical diameter of C. The radius of D, and the location of its centre, may best be found by trial and error: this will give a result practically as accurate as that of a geometrical construction, which may be made, but the process is long and tedious. The diameter of D must then be subdivided, by the scale if practicable, and if not by means of the dividers, in order to locate the centres of the remaining circles.

43. In Fig. 22 the horizontal and vertical diameters may be drawn with the T-square, and the inclined ones with the 45° triangle; but the work should afterward be carefully tested with the dividers, to make sure that the outer circle is accurately divided.

Produce IK to cut at B the horizontal tangent through A, making AB equal to AO. Then a line bisecting the angle ABO will cut AO in C, the centre of one of the larger circles required. Draw through C a horizontal line cutting OK in E: then $CE = CO$, and E is the centre of one of the smaller circles, each of which is tangent to the two adjacent larger ones as well as to the exterior circle.

44. The equilateral Gothic arch, Fig. 23, is drawn by describing about A and B, the extremities of the base, two circular arcs with radius AB, which intersect at C on the vertical

centre-line *CD*. The problem is to inscribe three tangent circles in this arc; the two lower ones will evidently be equal, and the centres may be found as follows: Set off on the prolongation of *BA* a distance measuring 3 on any scale of equal parts; at *E* set up a

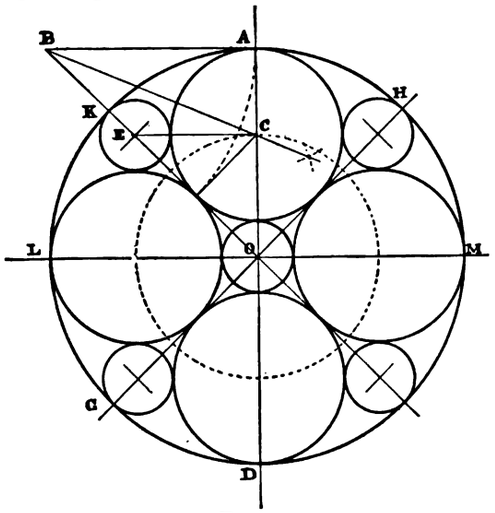


FIG. 22.

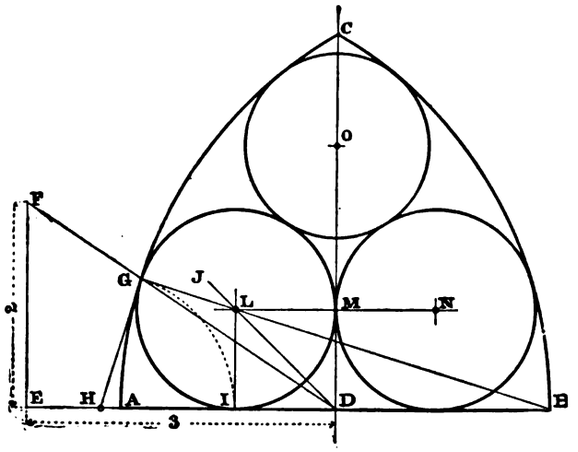


FIG. 23.

vertical *EF*, measuring 2 on the same scale, and draw *FD* cutting the arc *AC* at *G*. Draw *GB*, and also a line perpendicular to it at *G* (which is therefore tangent to the arc *AC*), and cutting *DE* at *H*. On *ED* set off $HI = HG$, and at *I* erect a vertical line cutting *GB* at *L*, the centre of one of the required circles. As a test, bisect the angle *ADC* by the line *DJ*, which should also pass through *L*. Draw through *L* a horizontal line cutting *CD* at *M*, and on it set off $MN = ML$: then *N* is the centre of the second lower circle. The radius of the third circle will be less than that of the others: its centre will obviously lie upon *CD*, and both centre and radius are practically best found by trial and error.

45. Fig. 24 is a panel ornamented with interlaced work, in which the pattern is composed wholly of circular arcs. The radii are uniform throughout, and it is apparent that all the

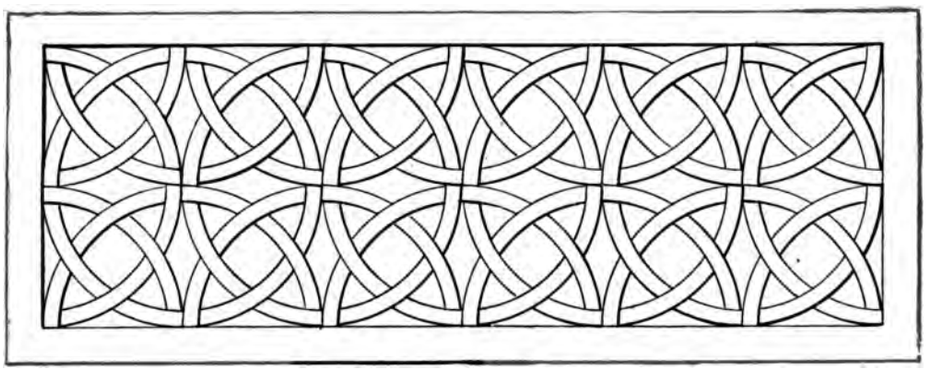


FIG. 24.

centres may be readily set out by using the scale alone as before described. This exercise is an excellent one for acquiring control of the compasses, since in order to produce a good

effect the shadow-lines must be of uniform strength as well as nicely graduated, and as in all work of this description the lines must meet without overrunning.

46. Figs. 25 and 26 are further exercises in "confined tangencies." In Fig. 25, having drawn the circle *O* and the trisecting centre-lines, we may draw the circles *A*, *B*, and *C*, with

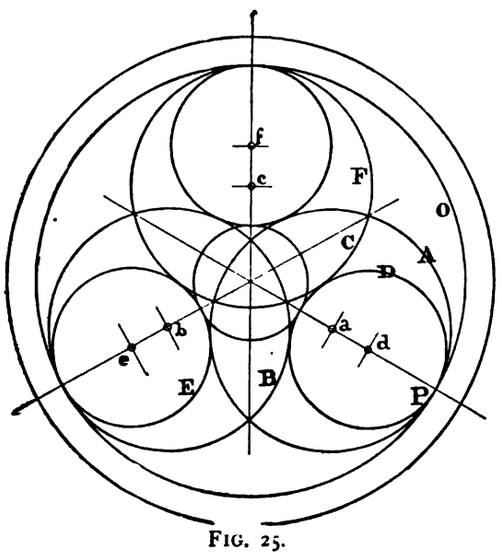


FIG. 25.

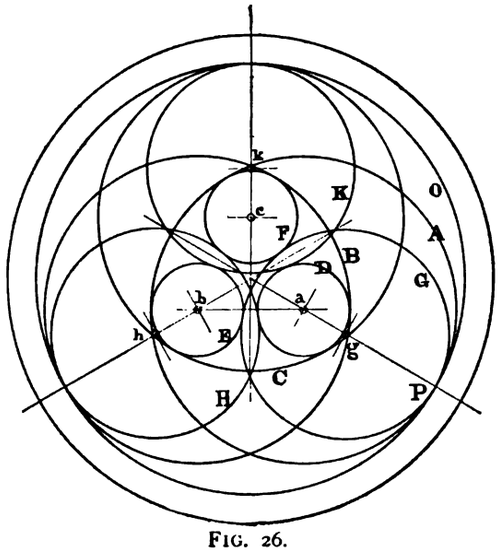


FIG. 26.

any assumed radius as *aP*. Then the circle *D* must touch the circle *O* at *P*, and also be tangent to *B* and *C*; its centre, which must lie on *aP*, as well as its radius, may best be found by trial. Fig. 26 is very similar in its nature; but in this case the radius of *A* is so large that

FIG. 27.

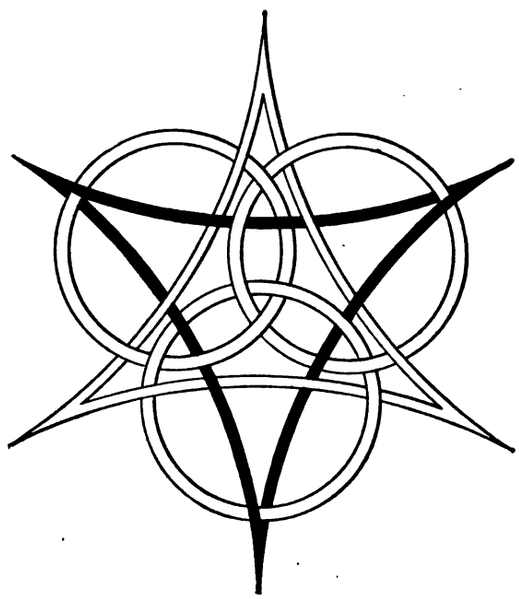


FIG. 28.

its centre *a* lies within both *B* and *C*. Another circle may therefore be drawn about *a*, internally tangent to *B* and *C*, whose radius may be found by drawing *ab* and producing it

to cut the circumference of A. Finally, by trial we find on aP a centre g, and a radius such that the circle G is tangent to O at the point P, and also touches the circles E and F, which are equal to D, and concentric with B and C.

47. Figs. 27 and 28 are merely fanciful designs of interlaced work, in which the centre-lines, which are necessary of course in laying out the work, are not shown. In regard to the former, it is sufficient to say that the centres of the three circles are at the vertices of the inner equilateral triangle, and the compasses must therefore be handled very lightly in order to avoid making unsightly holes in the paper and thus marring the finish. In Fig. 28 the vertices of the interlacing curvilinear triangles must of course lie at six equidistant points upon the circumference of a circle, and the centres of the arcs which form their sides lie upon the prolongations of the diameters passing through those points. The radii of these arcs is arbitrary: indeed, much in relation to the proportions and details of these exercises is purposely left to individual discretion, because training in judgment and forethought is quite as essential to success as that in manual dexterity. In both these exercises the broad black lines are to be drawn as explained in (**20**); and in Fig. 28 special care in inking in is necessary as to the six outer points, particularly in manipulating the shadow-lines upon these acutely intersecting arcs, which should not appear blunted, but terminate in knife-edges, sharp, clean, and well defined.

48. In Fig. 29, having described the outer and the inner circles, whose diameters are arbitrary, about the common centre O, divide the circumference of the latter into any number of equal parts at A, B, C, etc., and draw tangents to it at the points of subdivision.

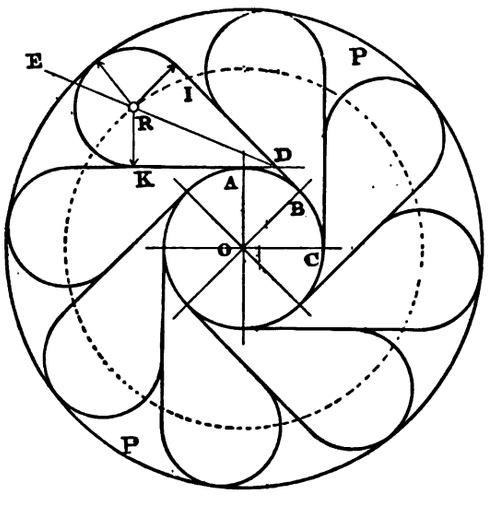


FIG. 29.

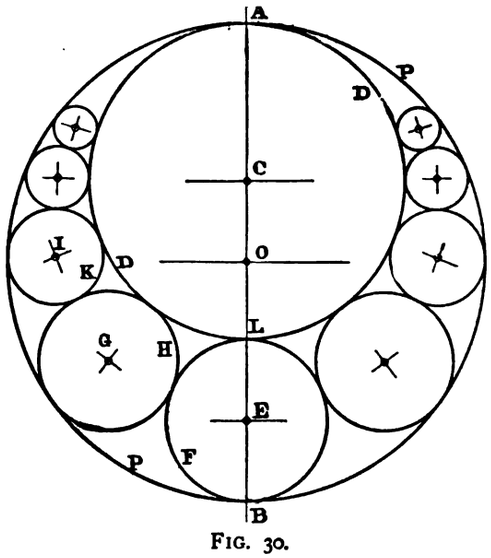


FIG. 30.

The tangent AK, produced to the right, intersects at D the tangent BI; bisect the angle KDI by the right line DE, on which find by trial the centre, R, of a circle which shall be tangent to the outer circle P, and also to the right lines AK, BI. A circle described about O through R contains the centres of all the small circles similarly tangent to P, which of course are equidistant from each other.

In Fig. 30, having drawn the outer circle P, and the vertical centre-line AOB, describe the

circle D tangent to P, with any radius CA taken at pleasure; bisect LB at E, which is the centre of circle F. Then find by trial the centre G, and the radius, of a circle H, tangent to P, D, and F; also of a circle K, tangent to P, D, and H, and so on as far as may be desired. It is easy to show that the centres of all circles tangent to P and D lie upon an ellipse, of which O and C are the foci, and AE is the major axis; but even the drawing of this ellipse would be of no practical advantage.

49. Outlines composed of Circular Arcs.—In drawings of mechanical subjects it is frequently desirable to make up curved outlines of a series of circular arcs of different radii, in order that the workman may readily copy them with the tools which are always at hand. This will in many cases give an approximation, sufficiently close for practical purposes, to a form which it would require much more time and trouble to lay out with perfect accuracy.

In Fig. 31, $EFGH$ is a rectangle divided by AC into two equal squares. In each square draw the diagonals, intersecting at B and D. About A as a centre describe the arc EF; about B describe the arc FG, then about C and D describe the arcs GH, HE; thus forming

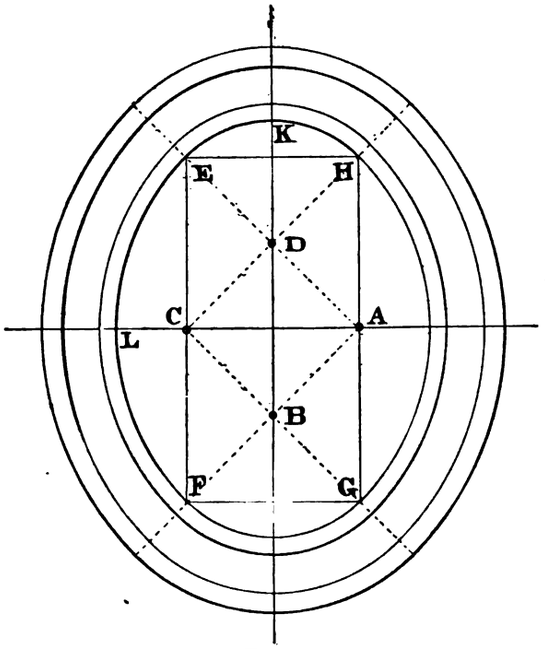


FIG. 31.

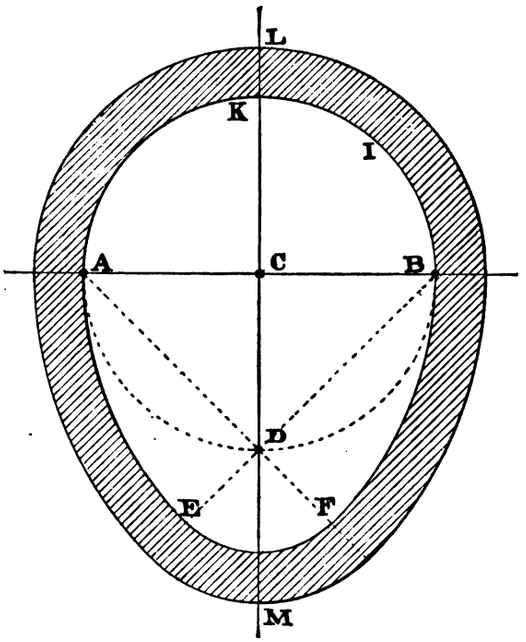


FIG. 32.

a closed figure, approximating in form to an ellipse. Using the same centres, with radii increased by a certain amount, this figure is surrounded by a narrow band of uniform width. Repeating the same operations with still greater radii, but *keeping the same centres*, the result is a representation of a picture frame with two raised mouldings.

It is clearly necessary that these various arcs should be truly tangent to each other, and the junctions imperceptible, as though each outline had been drawn by one continuous motion of the pen.

Relief is given by the use of shadow-lines: in regard to which it may be said that practically the portion LEK may be made of uniform thickness, the tapering of the line being

confined to the half-quadrants LF, KH; and the same holds true in relation to the other shadow-lines upon the mouldings.

50. Fig. 32 shows an approximation to an *oval* outline by means of circular arcs. Describe about C a circle cutting the horizontal diameter at A and B and the vertical diameter at D; draw AD, BD, and produce them. About A as a centre, with radius AB, describe the arc BF; about B with the same radius describe the arc AE, and complete the inner oval by drawing the arc EF about centre D. The outer oval is drawn by means of arcs *about the same centres*, but with radii increased by a definite amount assumed at pleasure. The space between the two ovals may then represent the outer wall of a sewer, and "sectioned" accordingly, the effect being heightened by the use of shadow-lines. As in the preceding example, the shadow-line may be made uniform from A to K, and tapered only from K to I, and from A to E: and similarly with regard to the exterior outline.

TENTATIVE AND MECHANICAL PROCESSES LEGITIMATE.

51. Before going farther, a little more may be said about the methods employed, to which allusion was made in (**3**). In some of the preceding explanations determinations by "trial and error" instead of by geometrical construction have been advised, which may to some appear at first glance inconsistent.

But in drawing we have to do only with the *representations* of magnitudes: thus a mathematical line, which has no actual thickness, must be represented by a mark of perceptible breadth. And the practical limit of accuracy is measured by the actual breadth of the finest visible line. Again, the ultimate test of the precision with which a geometrical operation has been executed lies in the answer to this question: Are the results which should follow actually obtained? To illustrate: Let it be required to draw a circle tangent to three given circles. The centre and radius may be determined by a geometrical construction; but if, when this has been made, the required circle sensibly fails to touch the given ones, it follows that an error has been committed. On the other hand, if by trial a circle be drawn which does touch the others, that fact proves that the centre and radius are those which *should* have been found by the construction; they may therefore be accepted as correct.

52. No positive rule can be laid down for determining which method should be adopted; but if the geometrical operations are complicated, or the conditions such as to make any of the steps dubious, owing to acute intersections or like contingencies, it is easy to see that their results may be less reliable than those of the tentative processes above suggested.

The use of the latter is evidently legitimate in laying out working drawings and the like, since in general the result only is to be represented. But even in making a diagram for the express purpose of illustrating a process, it is perfectly fair to make sure of the result by such means first, and to introduce the proper construction-lines afterward. Again, the draughtsman has often to perform operations for which there *is* no geometrical construction, as, for instance, in drawing a wheel with thirty-one teeth: he must divide the circumference of his circle into the given number of equal parts, and this can be done only by trial. Even if the subdivision can be made geometrically, as in constructing the pentagon, Fig. 16, the final test is by trial, to see that the chord is correct; and so, in general, the one method may be used as a check upon the other.

53. Closely akin to these are certain mechanical methods constantly employed by every expert draughtsman. It need hardly be said that he who is possessed of two trustworthy triangles must also be possessed of an evil spirit if he does not use them for drawing lines parallel or perpendicular to each other, instead of resorting to a geometrical construction. This is no more mechanical than laying off an angle by means of a protractor: in either case the precision of the work depends upon the perfection of the instruments and the skill with which they are used, and indeed the same may be said of drawing a straight line through two given points by means of a ruler. In doing this the edge of the ruler is set, not so as to coincide with either point, but at a small distance from each, the eye being able to judge with perfect certainty of the equality of these distances, or as it is technically expressed, of the "daylight," between the ruler and the points. And this judgment is equally reliable if one or both the points be replaced by a curve. In this way it will be seen that if it is required to draw a tangent to a given curve through a given point or in a given direction, or a tangent to two given curves, the operations may be performed with the ruler alone with as much precision as though the points of contact were determined by geometrical processes.

54. It may be accepted, then, that the eye can judge of the *fact* of tangency between a curve and a right line when the direction of the tangent is either assigned or fixed by some other condition, with a degree of accuracy equal to that attainable in any graphic operation whatever. And no argument is needed to show that it would be absurd not to take advantage, in drawing mechanically, of a fact which in numberless cases enables the draughtsman to save both time and trouble, without in the slightest degree affecting the reliability of the results. But it is to be understood that the *point* of tangency cannot be located by the eye with any precision, and must in all cases be determined by some process of construction.

CHAPTER II.

EXERCISES IN THE DRAWING OF NON-CIRCULAR CURVES.

55. It is often necessary, particularly in drawings of machinery, to construct with accuracy various mathematical curves; and some preliminary practice in this kind of work being desirable, the following chapter is devoted to explanation of some of the more important of these curves, and of various graphic processes relating to them. In these and other operations there is frequent occasion to rectify circular arcs, and to lay off, either upon circles of given radii, or so as to subtend given angles, arcs of given linear values.

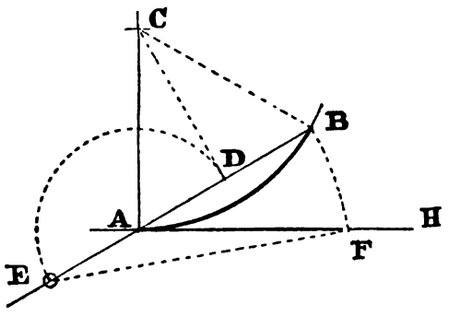


FIG. 33.

In such cases the following constructions, due to Prof. Rankine, are extremely convenient; the results are obtained much more expeditiously than by computation, with a degree of accuracy amply sufficient for all ordinary purposes.

56. I. *To lay off on a right line a distance approximately equal in length to a given circular arc.*

Let AB, Fig. 33, be the given arc, and AH its tangent at A. Draw the chord BA, and produce it; bisect AB in D, and set off AE equal to AD. About E as a centre, with EB as radius, describe an arc cutting AH in F: then $AF =$ arc AB, very nearly.

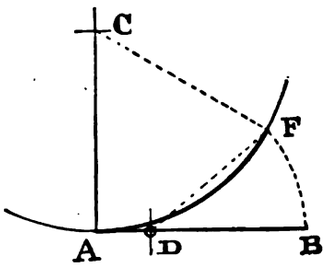


FIG. 34.

II. *To lay off on a given circle an arc approximately equal in length to a given right line.*

In Fig. 34, let AB, the given line, be tangent at A to the given circle. Set off $AD = \frac{1}{4}AB$, and about D as a centre, with radius $DB = \frac{3}{4}AB$, describe an arc cutting the given circle in F. Then arc $AF = AB$, very nearly.

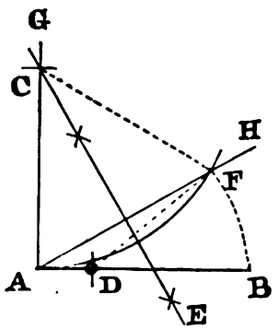


FIG. 35.

III. *To find the radius of an arc which shall subtend a given angle, and be approximately equal in length to a given right line.*

Let AB, Fig. 35, be the given right line. Draw AG perpendicular to AB; and also AH, making the angle BAH equal to half the given angle. Set off $AD = \frac{1}{4}AB$, and about centre D, with radius $DB = \frac{3}{4}AB$, describe an arc cutting AH in F. Bisect AF by the perpendicular EC, which will cut AG in C, the centre of the required arc AF.

57. Amount of the Error in the above Processes.—According to Prof. Rankine, the straight line is a little less than the arc in the application of either of these rules. He gives

the magnitude of the error as about $\frac{1}{900}$ part of an arc of 60°; but it varies as the fourth power of the subtended angle, and may be reduced to a very minute amount by subdivision. Thus, for an arc of 30°, the error will be $\frac{1}{900} \times \frac{1}{16} = \frac{1}{14400}$; and for one of 20°, only $\frac{1}{900} \times \frac{1}{81} = \frac{1}{72900}$. If, then, the arc, given or required, subtends an angle of over 60°, subdivision should be resorted to in practically applying either process.

The first two rules can also be applied to other curves than circles, provided that the change of curvature in the part to be dealt with be small and gradual.

THE ELLIPSE.

58. First Method.—About the centre *C*, Fig. 36, describe two circles whose diameters are respectively equal to the major and minor axes, *AB* and *MN*. Draw any radius at pleasure, cutting the inner circle in *D* and the outer one in *E*. Draw through *D* a parallel to *AB*, and through *E* a parallel to *MN*: the intersection *O* of these lines will be a point upon the ellipse. This is the most accurate of all methods for constructing this curve by points, all the intersections, *D*, *E*, *O*, being right angles.

To draw the tangent at a given point upon the curve.—Let *P* be the point: then by reversing the above process we find that *P* would have been determined by the radius *CGH*. At *G* and *H* draw tangents to the two circles, cutting the corresponding axes produced, in *L* and *R*, respectively: then *LR* is the required tangent at *P*.

Conversely, to find the point of tangency.—Suppose it required to draw a tangent through a given point *Q*, or parallel to a given line *XY*. The tangent is drawn mechanically as explained in (**53**): it cuts the axes at *R* and *L*. From *R* draw a tangent to the outer circle, from *L* a tangent to the inner circle; these should be parallel to each other, and the points of contact are found by drawing *CGH* perpendicular to both: then through *G* draw a parallel to *AB*, and through *H* a parallel to *MN*, which two lines will intersect in the required point of tangency *P* on the ellipse.

59. Cautionary Remarks.—Particular attention is called to these points, viz.:

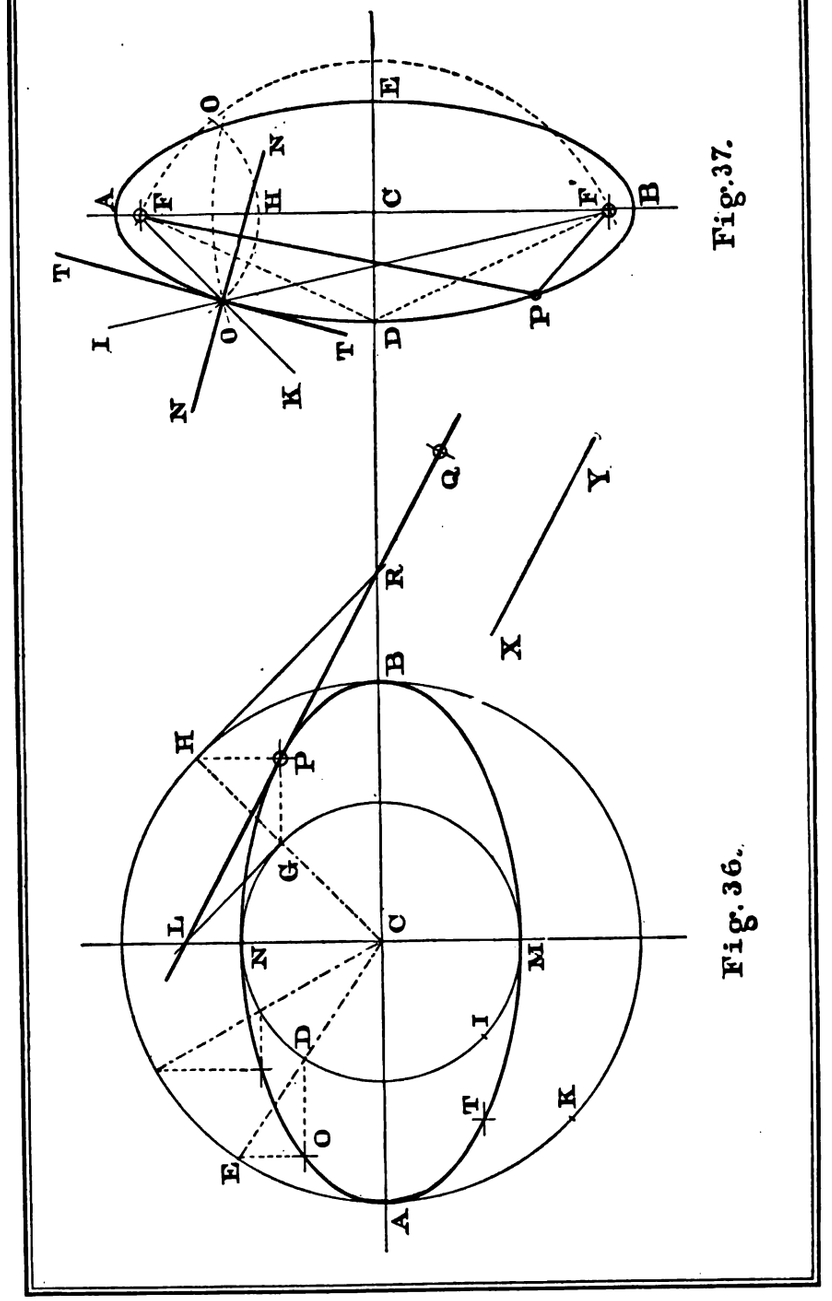
1. The radii, *CE*, etc., need not be equidistant, and no attempt to subdivide the circle should be made.

2. In construction, no radius should be drawn at all; for instance, set the triangle as if to draw *CK*, but mark only the points *I*, *K*: then very short lines only, intersecting at *T*, need be drawn. See (**4**) page 2.

3. The points determined should be nearer together where the curvature of the ellipse is most rapid; but the actual number is arbitrary. This applies to the construction of *any* curve by locating points.

4. For illustrating the process, two radii are sufficient: these should be made more prominent, as in the figure, than the perpendiculars and horizontals leading to the intersections upon the ellipse, which may be indicated by short full lines.

60. Second Method.—Let *C*, Fig. 37, be the centre, *AB* the major axis, *DE* the minor axis. About *D* with radius *AC* describe an arc cutting *AB* in the foci *F*, *F'*. About *F* as a centre describe an indefinite arc with any radius *FH*, greater than *AF* and less than *BF*. About *F'* describe another arc, with a radius $F'O = AB - FH$: this arc will cut the one first drawn in *O*, *O'*, two points of the required curve.


E
O
N
A
F
H
C
F'
B
T
I
O'
T'
D
P
N
K
Fig. 37.
Q
Y
R
X
B
H
P
G
L
C
N
M
D
I
T
K
O
E
A
Fig. 36.

This method is not eligible for the ordinary purposes of the draughtsman, because it involves much more labor than the preceding one, and the intersections of the arcs are in many cases too acute to be reliable. But it is of interest as depending upon the property of the ellipse that the sum of the focal distances is the same for every point upon the curve, and equal to the major axis; thus,

$$PF + PF' = OF + OF' = AF + AF' = BF + BF' = AB.$$

61. Third Method.—Upon this property, also, depends the operation of drawing the "gardener's ellipse" by the aid of a string and two pins. Let two fine pins be fixed in the drawing-board at F, F', Fig. 37; around these pass a loop of waxed sewing-silk, of which the total length is $AB + FF'$: if this loop be kept constantly taut by a pencil P, the latter in moving will trace the ellipse.

To draw a tangent at any point, as O: Produce FO and $F'O$, and bisect the exterior angles FOI, $F'OK$ by the line TT. To draw the normal at the same point, bisect the angles IOK, FOF' by the line NN. Obviously the axes cut the curve normally at their extremities A, B, D, E.

62. Fourth Method.—Fig. 38 illustrates the principle of a common elliptographic

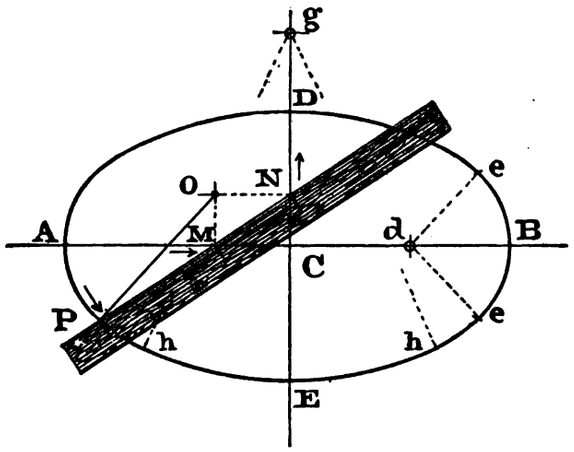


FIG. 38.

trammel. The three points P, M, N are in one right line, the distance PM being equal to CD, and PN equal to CA. Keeping M always upon the line of the major axis, and N upon the line of the minor axis, the point P will at all times lie upon the ellipse.

This method is extremely convenient when the greatest precision is not required; the three points being selected upon the graduated edge of a scale, or marked upon the edge of a smoothly cut strip of paper.

To draw the normal at P. At M draw a perpendicular to AB, at N a perpendicular to DE: these perpendiculars intersect at O, and OP is the normal required; and this is independent of the position of the point P.

63. Fifth Method.—To inscribe an ellipse in any given rectangle, Fig. 39. Join the middle points of the opposite sides by the right lines AB, EF: these will be the axes, and intersect in the centre C.

Divide the semi-minor axis *CF*, and the half side *GF* of the rectangle, into the same number of equal (or proportional) parts. Through the points of subdivision on *CF* draw right

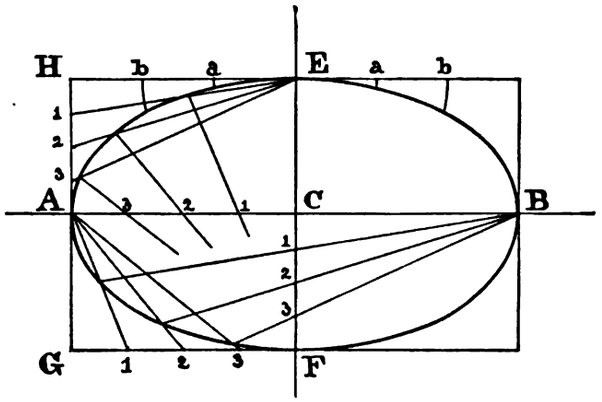


FIG. 39.

lines from *B*, and produce them to intersect the lines drawn from *A* to the corresponding points on *GF*. These intersections will lie upon the ellipse.

Or, divide the semi-major axis *AC* and the half side *AH* in like proportion, and proceed in a similar manner, the two series of intersecting lines being drawn from *E* and *F*, the extremities of the minor axis.

64. The same process is applicable when it is required to inscribe an ellipse in any given parallelogram, as shown in Fig. 40; but in this case *AB*, *EF* are not the axes.

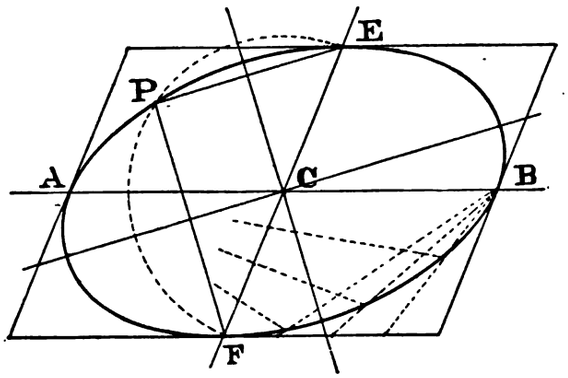


FIG. 40.

They are, however, conjugate diameters, for each is parallel to the tangents at the extremities of the other; and since the parallelogram can always be constructed if *AB* and *EF* are given, we have thus a simple and ready method of constructing the ellipse upon any pair of conjugate diameters.

In order to determine the direction of the axes, describe about the centre *C* a circle upon either of the conjugate diameters, as *EF*: the circumference cuts the ellipse in *P*, and the supplementary chords *PE*, *PF* are parallel to the axes.

65. Sixth Method.—To construct the ellipse by means of ordinates of the circle. In Fig. 41, let it be required to draw the ellipse of which *CP* is the semi-major and *CR* the semi-minor axis.

Describe a circle with radius $AE = CR$, and divide *CP* and *OA* into any number of proportional parts. At each point of subdivision erect a perpendicular to *CP*, equal to the

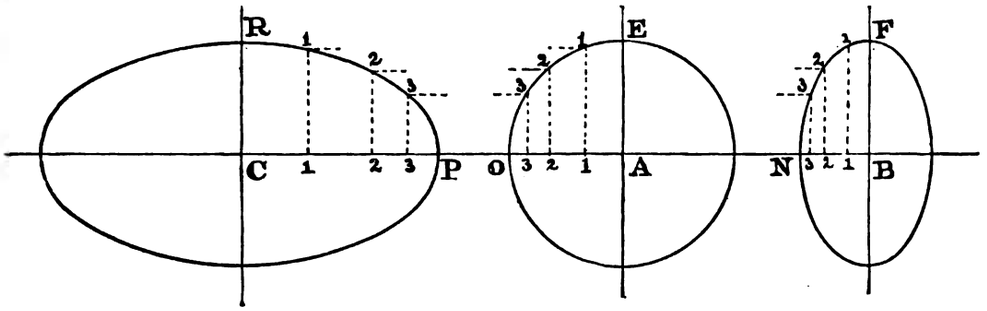


FIG. 41.

ordinate of the circle at the corresponding point of *OA*: the curve *PR* thus determined is the required ellipse.

Or, *AE* may be made equal to the semi-major axis, as *BF*: then if *OA* and the semi-minor axis *BN* be similarly subdivided, the ordinates of the circle will be equal to the corresponding ordinates of the ellipse *NF*.

66. In a given ellipse, to find the conjugate to a given diameter.

In Fig. 42, let *PO* be the given diameter. Draw any chord *EF* parallel to *PO*, and bisect it: then the required conjugate diameter *MN* passes through the point of bisection, and *TT*, the tangent at *P*, is parallel to *MN*.

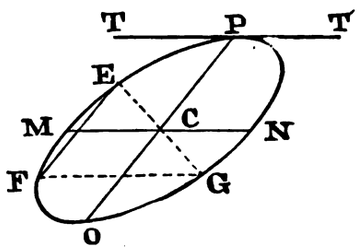


FIG. 42.

Otherwise: Draw the chord *EF* parallel to *PO*, and also the diameter *EG*: then *MN* and *TT* are parallel to the supplementary chord *FG*.

67. It is not, of course, intended or expected that an ellipse should be drawn by each of these various methods merely as an exercise: it is proper, however, to illustrate them here, since all these different properties of the curve will be found applicable at one time or another in subsequent operations.

In making the constructions for practice only, it is recommended that two ellipses should be drawn on each sheet, the major axis of one being horizontal, that of the other vertical; that these should be laid out by different methods; and particularly that they should be made of quite different eccentricities: for while the law of the curve is always the same, the actual form is capable of infinite variation, and the course here advised will give greater practice in the use of the sweeps.

PRACTICAL SUGGESTIONS IN REGARD TO THE DRAWING OF CURVES.

68. A sufficient number of points having been determined, the curve should first be sketched in very lightly with the free hand; if there be any serious error in the location of

any points, it is likely to be thus detected. The contour should then be pencilled in more firmly by aid of the "sweeps" or curved rulers, which also are used in finally drawing it with the pen. The pencil line should be fine and clear; if the ink line be made heavy, half its thickness should be outside and half inside of the exact contour: see (**32**) and (**33**).

Approximating Circular Arcs.—It is not only legitimate, but advisable, to make use of the compasses in inking in. By trial a radius may be found with which an arc can be drawn, having its centre upon the major axis, which will agree so closely with the ellipse for some distance on each side of the vertex, that the difference is absolutely imperceptible even when the line is as fine as possible. Thus in Fig. 38 the arc *ee* may be drawn about the centre *d*; and in like manner *hh* is an arc described about the centre *g*, on the line of the minor axis. The same radii being used for arcs through the opposite vertices, perfect symmetry is ensured, and there remain only four portions equal to *eh*, to be drawn with the sweeps. The points, *ee*, *hh*, etc., should of course be previously set off, equidistant from the vertices, to secure equality of length in the opposite arcs.

This process is also applicable to many other curves, as the parabola, hyperbola, sinusoid, etc., which are symmetrical about an axis.

69. In the case of a very long and narrow ellipse, the centre corresponding to *g* in Fig. 38 may become inaccessible; and the part *hh* of the curve must also be drawn by means of the sweeps. It is a very common error to suppose that in any case accuracy can be secured by adjusting a curved ruler to draw from *E* to *h* on one side, and then reversing it to draw from *E* to *h* on the other. Even if the tangent at the vertex be first drawn in pencil, the attempt to do this will almost certainly result in the formation of a "hump" or "broken back" at *E*. The proper course is indicated in Fig. 39. Draw the tangent at *E*: then about *E* as a centre describe arcs cutting both the curve and the tangent on opposite sides of the vertex, as at *a*, *a*, *b*, *b*. The eye can judge accurately of the equality of the corresponding intercepts, and the sweep can thus be adjusted to draw at one stroke of the pen an arc of the curve extending some distance each way from the vertex.

70. In using the sweeps, certain precautions are requisite in order to make a smooth and "fair" line. Beginners are apt to set the sweep so as to draw a line through three or four points, and in readjusting it, to begin at the *last* point of the line just drawn, and set it so as to agree with the next three or four, and so on. The result is likely to be painfully conspicuous by reason of "humps"—the various sections of the curve thus traced not being truly tangent to each other. To avoid this: 1. *Never draw quite as far as you think you can* at one setting of the sweep; in other words, stop before the sweep deviates sensibly from the curve. 2. In readjusting, always set the sweep *so as to coincide* for a little distance with the portion of the curve already drawn.

71. Copying by Transferring or Impression.—The ellipse is composed of four similar and equal arcs, or quadrants. If one of these has been accurately laid out by any of the methods described, the labor of constructing the other three may be saved by the following expedient: Suppose, for instance, that the quadrant *AE*, Fig. 39, has been drawn with precision: upon a piece of thin transparent paper make a *careful* tracing of it with a sharp-edged, moderately hard pencil, and trace also the axes *AC*, *EC*. Turning this paper over, and adjusting it by these centre-lines, go over the visible contour again with a firm pressure:

this will leave a faint trace of the quadrant *EB*, and will also make a mark on the reverse side of the thin paper; which by like treatment will yield an impression of the quadrant *BF*; and *FA* may be also similarly transferred. This simple proceeding can be applied in the case of many other curves composed of similar and symmetrical branches, as well as in the copying of others which are to be reproduced in several different positions. Much labor in the way of construction can thus be saved; but in the various tracings the sweeps must be used as conscientiously and as carefully as though the results were final.

THE PARABOLA.

72. The Parabola, Fig. 43, is a curve every point of which is equally distant from a given point *F*, called the focus, and a given right line *DD*, called the directrix. It is therefore svmmetrical about the axis *OFC* perpendicular to *DD*, and its vertex *V* lies at the

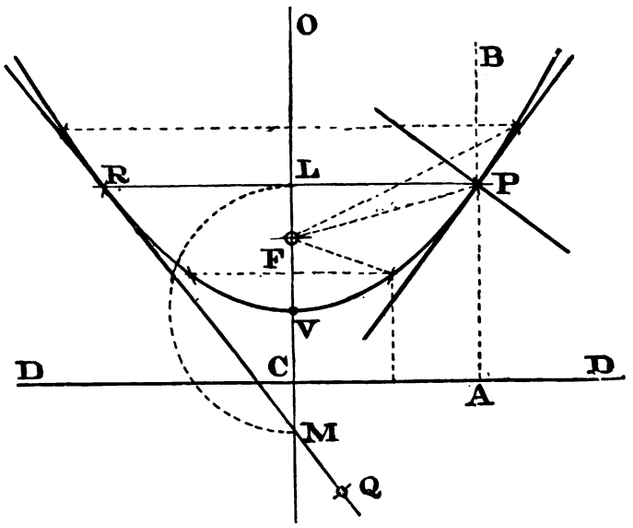


FIG. 43.

middle point of *FC*. Draw any line parallel to *DD*, as *RLP*: then the points in which this line is cut by an arc described about *F*, with a radius equal to *LC*, will lie upon the curve.

To draw a tangent at any point, as P: Draw *FP*, and also *PA* perpendicular to *DD*: then the required tangent bisects the angle *FPA*, and the normal bisects the angle *FPB*.

Otherwise: Let *R* be the given point. Draw *RL* perpendicular to the axis, and on the axis set off $VM = LV$: then *MR* is the required tangent.

To draw a tangent through a point without the curve, and find the point of tangency: Let *Q* be the given point. Draw the tangent mechanically as explained in (**53**), and produce it to cut the axis in *M*; set off on the axis $VL = VM$, and through *L* draw a parallel to *DD*; this will cut the tangent in the required point *R*. The same process applies to the drawing of a tangent in a given direction.

73. Second Method.—In Fig. 44, let *V* be the vertex, *VO* the axis, and *P* a point through which the curve is to pass. Draw *PR* perpendicular to *VO*, and make $QR = PQ$. On the axis set off $VL = VQ$; draw *PL* and *RL*, divide them into the same number of equal parts, number the points of division in opposite directions, and join the points correspondingly numbered, as 1, 1, 2, 2, etc.: the lines thus drawn will be tangents to the required curve.

To find the point of tangency on any one of these lines, for instance 1, 1. This line cuts the axis at N; set off on the axis, $VK = VN$, and draw KB perpendicular to VO; this will cut 1, 1, in the required point B.

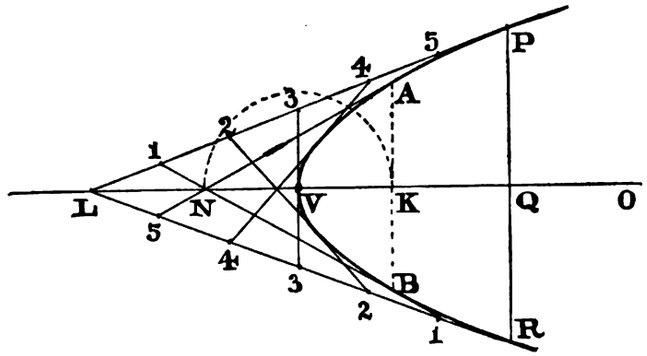


FIG. 44.

74. Third Method.—In Fig. 45, let V be the vertex, VO the axis, and P a point through which the curve is to pass. Draw PO, VA, perpendicular to the axis and equal to each other, and join AP. Divide VA and AP into any number of proportional parts; through the points

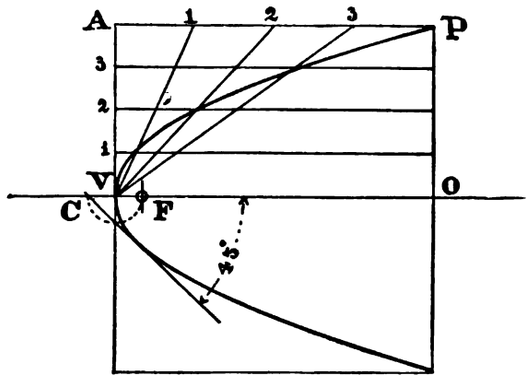


FIG. 45.

of division on VA draw parallels to the axis, and from those on AP draw lines to the vertex: the intersections of lines thus drawn through corresponding points on VA and AP will lie upon the parabola VP.

To find the focus and directrix: Draw a tangent to the curve, making an angle of 45° with VO (**72**); this cuts the axis at the point C of the directrix DD, which is perpendicular to VO. On the axis set off $VF = VC$: then F is the focus.

75. Application.—A pleasing application of this curve to practical purposes is found in the pointed arch, Fig. 46: AC being the span and BD the rise, the outer line of the arch is composed of the two parabolas AB, BC, of which the common axis is AC, and the vertices are A and C. These may perhaps be best constructed by the method of Fig. 45, as indicated by the rectangle $AEBD$, and the two lines intersecting in x.

The inner curves *ab*, *cb* are not true parabolas, but *parallels* to AB, BC: that is, the normal distance between the outer and inner curves is everywhere the same. These interior

curves are best drawn thus: Strike with the bow-pencil a series of arcs with a radius equal to the assumed breadth *Aa*, all the centres being on the parabola *AB*. Then by means of the sweeps draw the *envelope* of these arcs, that is, a line tangent to them all.

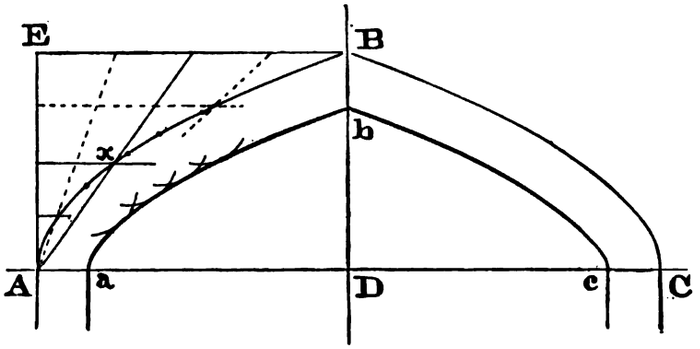


FIG. 46.

Note.—Points on this interior curve might be found by drawing normals to the parabola *AB* by methods previously indicated, and setting off on each the assumed distance *Aa*. But the process just described is far less laborious, and if the number of arcs be equal to that of the points, it is quite as accurate, if not more so.

THE HYPERBOLA.

76. The Hyperbola is a plane curve generated by the motion of a point subject to the condition that the *difference* of its distances from two fixed points called the foci shall always be equal to a given line, whose length must be less than the distance between the foci.

In Fig. 47 set off on the horizontal line $CF = CF'$, and let F, F' be the foci: also set off

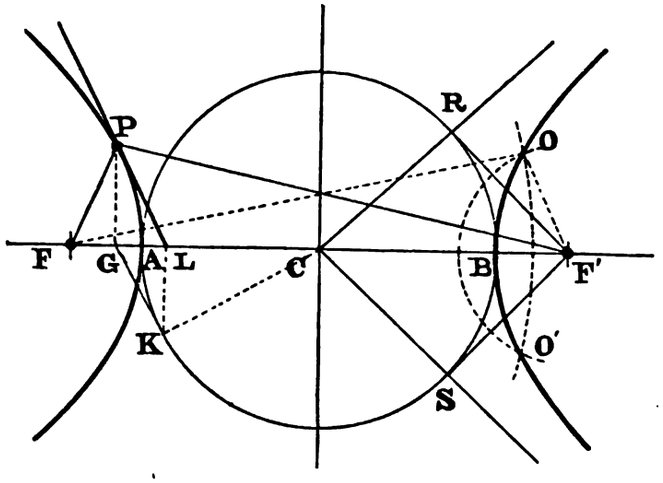


FIG. 47.

$CA = CB$, and let AB be the given constant difference. Clearly, then, $FB - BF' = AF' - AF = AB$; therefore A and B lie on the curve. With any radius FO greater than FB, describe an arc about F as a centre: then about F', with a radius $F'O = FO - AB$,

describe another arc, which will cut the one first drawn in two points O, O', of the hyperbola. Since with the same radii arcs may be described about the other foci, it follows that the curve has two equal and opposite branches; which are infinite, because FO may be of any length.

The point C is called the centre, and the line AB the major axis, to which the minor axis passing through C is perpendicular.

To draw a tangent at any point of the curve, as P: Draw PF, PF', and bisect the angle between them; the bisector is the required tangent. *Otherwise thus:* Describe a circle upon AB as a diameter, let fall a perpendicular PG upon the major axis, and from its foot G draw a tangent to the circle. From K, the point of tangency, let fall a perpendicular KL upon the major axis; through its foot L draw LP, the tangent required. By reversing this process the point of contact may be found, when the tangent is drawn mechanically (**72**), through a given point not upon the curve, or parallel to a given line.

To find the asymptotes: From either focus, as F', draw tangents to the circle described upon diameter AB; find the points of contact R and S: then CR and CS are the asymptotes.

77. Second Method.—In Fig. 48, let C be the centre, AB the major axis, and O a point through which the hyperbola is to pass. Describe upon AB the semicircle ADB, and

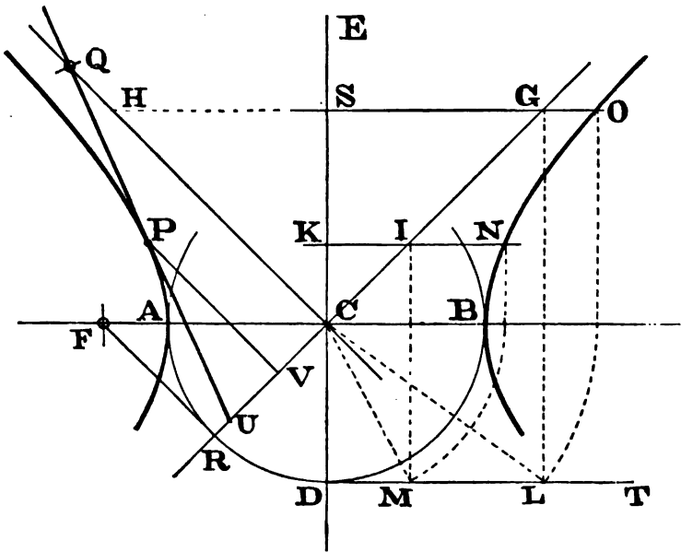


FIG. 48.

draw DCE perpendicular to AB, also DT tangent to the semicircle. Draw OS perpendicular to DE, and with radius OS describe about C an arc cutting DT in L; on SO set off $SG = DL$: then CG is an asymptote to the curve. Draw any line KI parallel to AB, cutting CG in I, and produce it; set off on the tangent, $DM = KI$, then on the prolongation of KI set off $KN = CM$, and N will be a point on the hyperbola.

To find the focus: Produce GC to cut the semi-circumference in R, at which point draw a perpendicular to GR; this will cut the line of the major axis in the focus F.

To draw a tangent at any point on the curve, as P: Draw PV parallel to the asymptote

HC, cutting the other asymptote *GR* in *V*. On *GR* set off $VU = CV$, and draw *PU*, which will be the required tangent.

To find the point of contact when the tangent is given: Suppose *PU* to have been drawn, mechanically (**72**), tangent to the hyperbola. Produce the given tangent to cut one asymptote, *GR*, in *U*, and the other one, *HC*, in *Q*. Bisect *QU* in *P*, which will be the point of tangency sought.

To draw the hyperbola through a given point, the asymptotes and the directions of the axes being known: This may be done by reversing the construction of Fig. 48. Thus, *CG* and *CH* being the given asymptotes, let it be required to draw the hyperbola through the given point *N*; the major axis to be horizontal and the minor axis vertical. Draw *NK* perpendicular to the minor axis *CE*, cutting the asymptote *CG* in *I*; through *I* draw a parallel to the minor axis, intersecting at *M* an arc described about *C* with radius equal to *KN*; through *M* draw a horizontal line, cutting the line of the minor axis in *D*: then *CD* = semi-major axis, and the curve can be completed as before.

78. Third Method.—Given, in Fig. 49, the major axis *AB*, and *P* a point in the required curve. Draw *PO*, *BE* perpendicular to *AB* and equal to each other, and join *PE*.

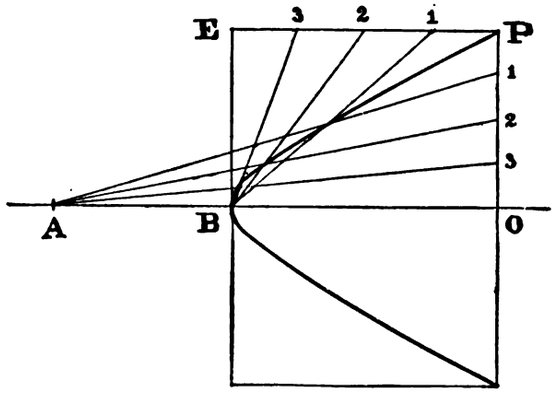


FIG. 49.

Divide *PO* and *PE* into the same number of equal (or proportional) parts, numbering the points of division from *P* on each line. From *A* draw lines to the points upon *PO*, and from *B* lines to the points upon *PE*: the intersections of the lines thus drawn to corresponding points of division, as for instance *A*1, *B*1, will lie upon the hyperbola required.

DRAWING OF ROLLED CURVES.

79. Rolled Curves, Roulettes, or **Epitrochoids,** are curves described by points carried by one line which rolls upon another, the latter being fixed. The line which carries the tracing-point is called the *generatrix* or *describing-line*, and the fixed one is called the *directrix* or *base-line;* either of these may be straight, or both may be curved.

The nature of perfect rolling contact may be best seen by a study of that which is not

perfect. The polygon in Fig. 50 rolls along the fixed right line with a hobbling motion. In the position shown, it is clear that if there is to be no sliding the point A must be at rest, and the motion indicated by the arrow must consist in a rotation of the whole figure about A as a fixed centre, until B reaches M, and the side AB coincides with LM. The polygon will then turn about B as a centre, and so on; its perimeter measuring itself off upon the right line. If the number of sides be increased, the hobbling will be diminished, and if the number becomes inconceivable, it will be imperceptible. The broken outline then becomes the dotted curve, to which the right line is tangent, and the change from one centre of rotation to another goes on continuously. But what is true up to the limit holds true at the limit, and the fact remains, that at any instant the point of contact is at rest, and every point in the figure is at that instant *turning about that point of contact as a fixed center.*

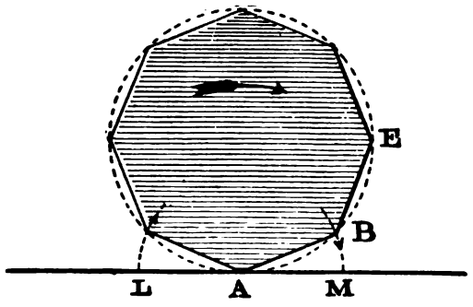


FIG. 50.

80. And upon this fact depends the readiest and most reliable known method of drawing the curves in question. In Fig. 51 AA is a curved ruler fixed to the drawing-board,

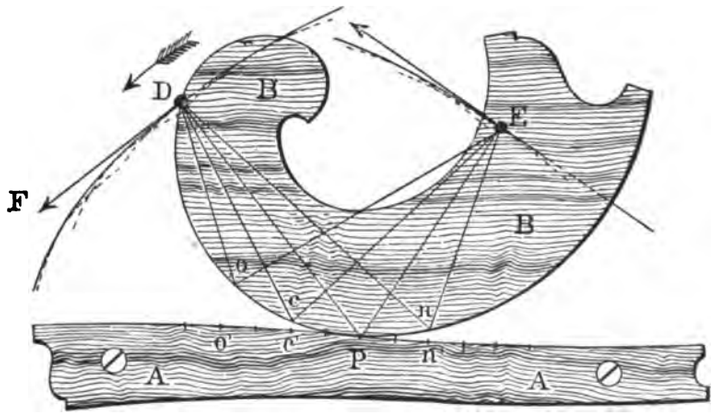


FIG. 51.

and BB is a free one rolling along it. Let a pencil be fixed to and carried by the latter, either in the contact edge as at D, or at any distance from it, as at E. Since P, the present point of contact, is the instantaneous centre of rotation, the point D is at the instant moving in the direction DF, perpendicular to the contact radius DP. Therefore DF is tangent to the path of D, traced as the ruler BB rolls; but it is also tangent to the circular arc whose centre is P and radius PD, consequently the path of D is also tangent to that arc.

Now, let the arcs Pc, Po, of BB, be equal to the arcs Pc', Po', of AA: then cD will be contact radius when c reaches c', and oD when o reaches o'. If then we describe, with these radii, circular arcs about c' and o', the curve traced by D will be tangent to those arcs; and that traced by E will be tangent to arcs about the same centres, with PE, cE, and oE as radii.

THE CYCLOID, EPICYCLOID, AND HYPOCYCLOID.

81. The Cycloid is traced by a point in the circumference of a circle which rolls upon its tangent.

In Fig. 52 find the length Aa' of a convenient fraction Aa of the circumference, (see **56**); step this off the required number of times upon the tangent, making AE equal to the semi-circumference. Divide each into the same number of equal parts, draw chords from P to the points of division on the semicircle, with which as radii strike arcs about the corresponding points on AE: the cyloid is tangent to all these arcs. The more numerous the arcs, the more perfectly is the curve mapped out.

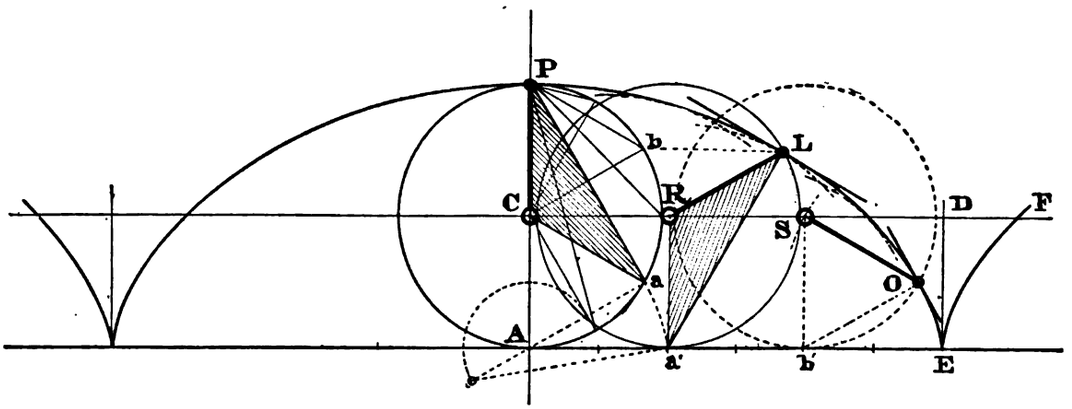


FIG. 52.

To find points on the curve: By the above process no points on the cycloid are located; the curve touches all the arcs, but the points of contact are not known; nor is it necessary, for the purpose of merely drawing the cycloid, that they should be. But if desired, they may be found thus: When aC becomes contact radius, it has the position $a'R$ perpendicular to AE; but the angle aCP remains unchanged. Therefore make the angle $a'RL$ equal to it; then RL is the new position of the *generating radius* CP, and L is a point on the cycloid. Also, $a'L$, the *instantaneous radius*, is normal, and a perpendicular to it at L is tangent, to the curve.

Conversely: Let O be any point on the curve; about this as a centre describe an arc with radius equal to CP. This arc cuts CD, the path of the centre of the rolling circle, in S: then OS is the generating radius; Sb', perpendicular to AE, is the contact radius; and $b'O$ is normal to the cycloid.

82. The Epicycloid.—The describing circle in Fig. 53 rolls upon the *outside* of another whose centre is G. Draw the common tangent at A, set off upon it the length of Aa (any convenient fraction of semi-circumference AP), and find (**56**) the arc of the base circle equal to that length. Step this off as many times as are necessary upon the base circle, making arc AE = semi-circumference AP. The curve is drawn by tangent arcs in the same manner as the cycloid.

The path of the centre C is in this case another circle whose centre is G, and the contact radii $a'R$, $b'S$ are prolongations of the radii Ga', Gb' of the base circle; which slightly

modifies the processes of finding the point of the generated curve corresponding to a given point of the rolling contact, and the converse.

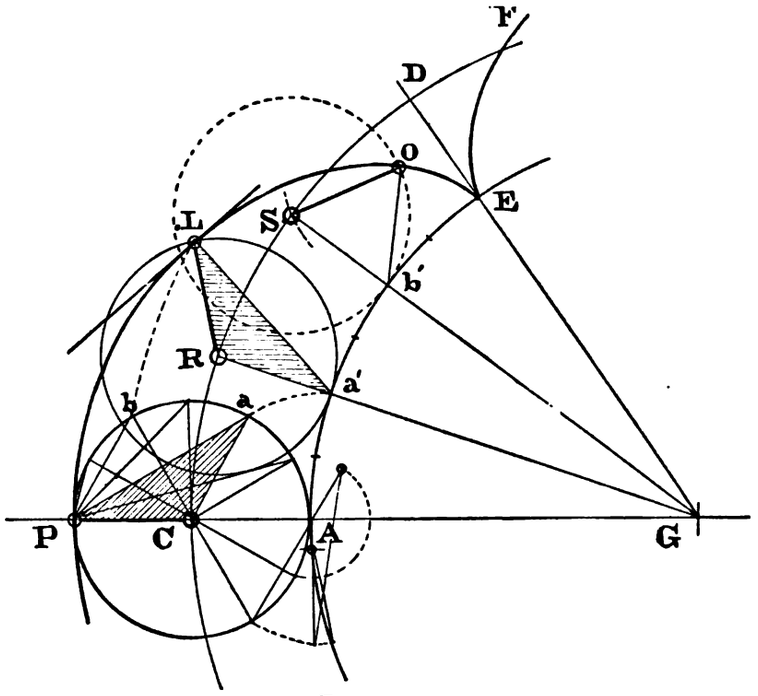


FIG. 53.

83. The Hypocycloid.—Traced, as shown in Fig. 54, by a point in the circumference of a circle rolling *inside* a larger one. The construction is in all respects the same as in

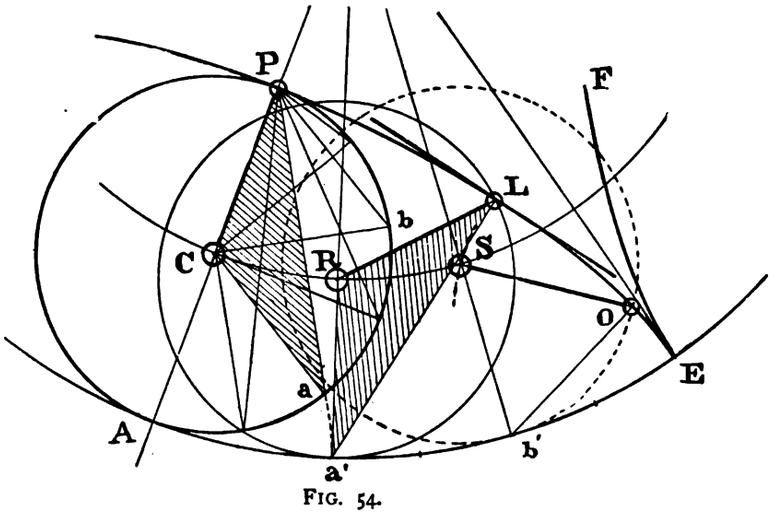


FIG. 54.

the case of the epicycloid, and as the diagrams are lettered to correspond throughout, no further explanation is needed.

In all three of these curves, if the rolling continues beyond E, a new branch springs up, which is perfectly symmetrical with EL.

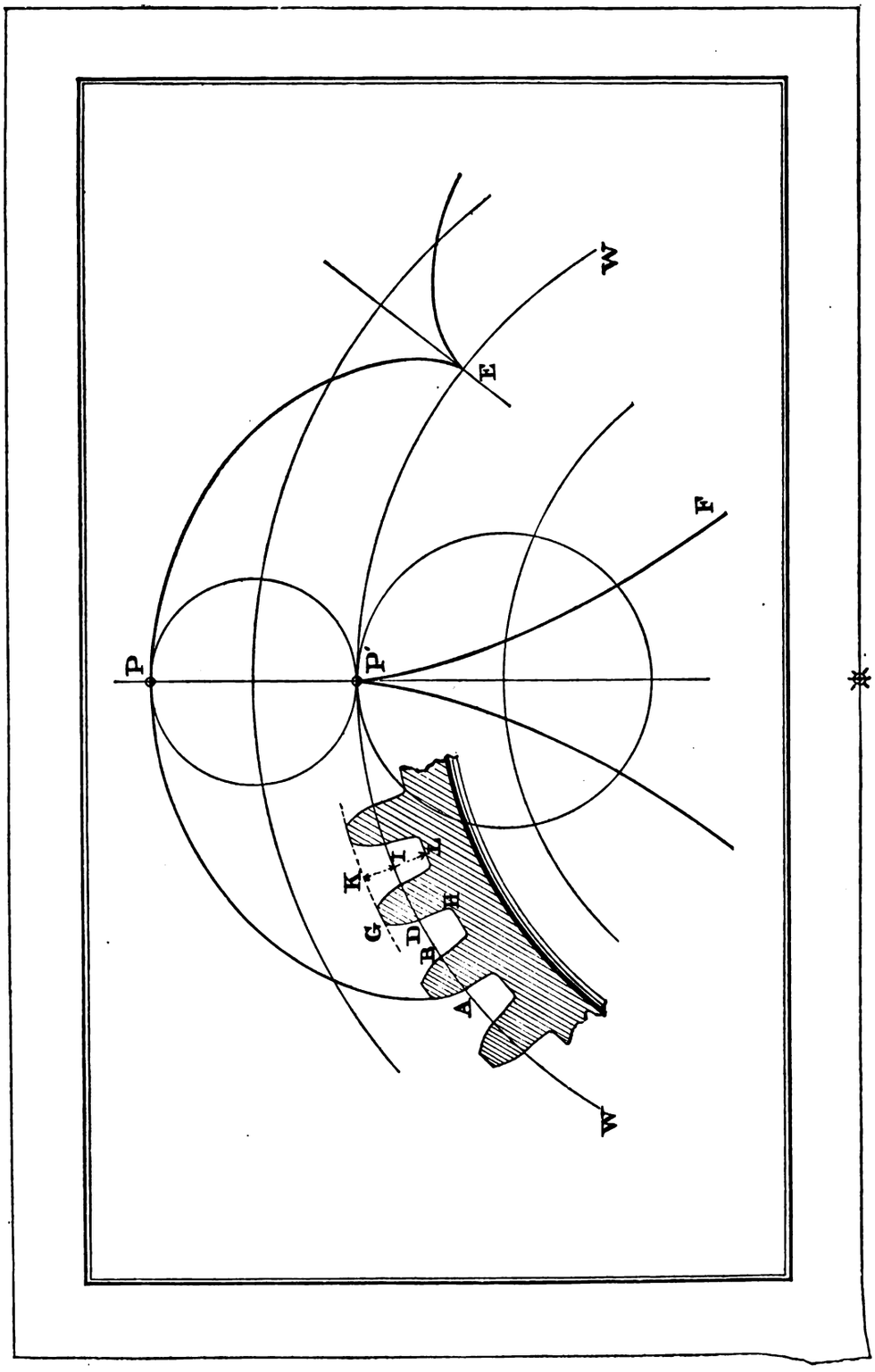


FIG. 55.

It is particularly to be noted that these branches are *tangent* to *ED*, and therefore to each other, at *E*; and that special care should be taken in constructing those parts of the curves which lie in this immediate neighborhood, not only because the change in the rate of curvature is here most rapid, but because they are the parts most frequently used in practical applications.

84. Spur-wheels with Epicycloidal Teeth.—Separate diagrams have been given in illustration of the epicycloid and hypocycloid, in order to make the construction clear. But these may be satisfactorily combined in one exercise, showing the application of these curves in forming the teeth of a wheel, as in Fig. 55. In laying out a spur-wheel, the first step is to draw the *pitch circle*, of which *WW'* is a part; the circumference of this circle is then divided into as many equal parts as the wheel is to have teeth, which determines the *pitch arc AD*, embracing a tooth and a space; and the space *ED* should be a little greater than the thickness of the tooth *AB*: the difference, say $\frac{1}{24}$ to $\frac{1}{30}$ of the pitch, is technically called *back-lash*.

The *face*, *DG*, or part of the tooth which lies outside the pitch circle, is, as shown, a part of the epicycloid *APE*; the flank, or part which lies inside, is a portion of the hypocycloid *PF*; and the describing circles for these may be of equal diameters or not, at pleasure. But if two wheels are to gear together, the same describing circle must be used for the faces of the teeth upon one wheel and the flanks of those on the other, and *vice versa*. The whole height of the tooth, *LK*, may be from $\frac{2}{3}$ to $\frac{3}{4}$ of the pitch, *LI* being greater than *KI* in the proportion of say six to five.

85. It is seen then that in laying out the teeth of wheels only small portions of the epicycloids are used; so that it is not necessary that the divisions of the describing circles used in constructing those curves should be aliquot parts of their circumferences. But it is necessary to have equal arcs set off on all the circles employed, and this may be very readily done as shown in Fig. 56. On the tangent at *A*, set off by the scale, *AB* = 1, *BC* = 3, taking care that *AC* does not exceed the radius of the smallest circle.

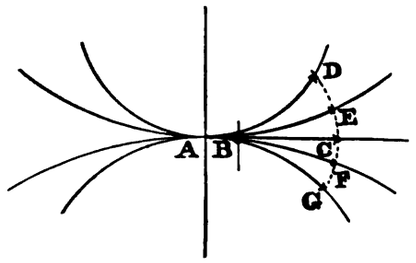


FIG. 56.

Then with centre *B* and radius *BC* describe an arc cutting the four circles, thus determining the four arcs *AE*, *AD*, *AF*, *AG*; which being each equal to *AC* (**56**), will be equal to each other.

86. The curves forming the outline of one side of a tooth having been accurately constructed, and carried well beyond the limits of the proposed height, the teeth may be very expeditiously drawn by the device shown in Fig. 57. A mould or template of the exact form of the contour turns freely about a fine sewing-needle fixed in the drawing-board at the centre of the wheel. The edges of the teeth being set out on the pitch circle, the template is set to coincide with each of these points in succession, until the left-hand sides of all the teeth are drawn, when the template is reversed in order to draw the right-hand sides.

Such a template may be made of thin wood like white holly, to which the contour is easily transferred as explained in (**71**). But one equally serviceable may be made with less

labor of Bristol-board, upon which the epicycloids may be constructed directly; the pitch circle, and the centre line of the wheel as well as its centre, should be marked in fine lines, after which the working edge of the template may be cut nearly to the line with a sharp

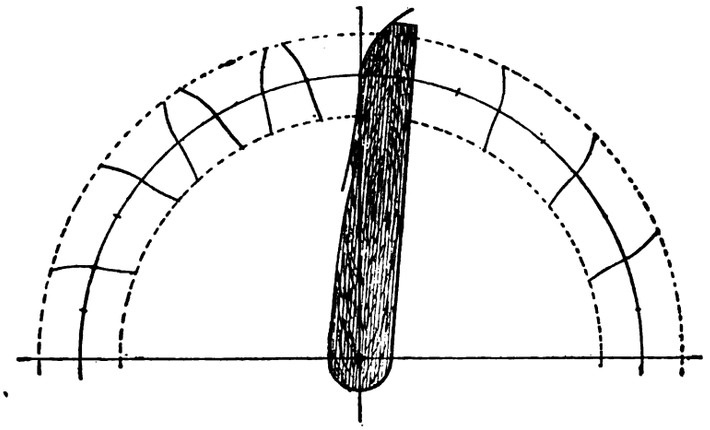


FIG. 57.

knife. Then shellac the template on both sides, and when dry it can be worked to the precise contour with a file and sand-paper. To use such a template with the pen, gum a bit of card to the back, a little away from the edge, so as to keep it slightly raised off the surface of the paper.

THE INVOLUTE OF THE CIRCLE.

87. The Involute is in a sense the converse of the cycloid, being generated by the rolling of a tangent line upon a circle. Thus in Fig. 58 the ruler, carrying in the line of its edge the pencil *P*, while rolling around the cylinder describes the curve under consideration.

It may also be regarded as generated by unwinding a fine inextensible thread from a cylinder: the thread being always taut and always tangent to the circumference, its length is always equal to that of the arc from which it was unwound. Thus, beginning at *O*, make the tangents *BE*, *AP*, *DF*, respectively equal to the arcs *OB*, *OBA*, *OBAD*, and so on: then the curve passes through the extremities *E*, *P*, *F*, *G*, etc., of these tangents; intermediate points may be found in like manner. The tangent *OG*, then, will be equal to the circumference of the circle, and if the unwinding be continued, a spiral will be formed; the distance between the successive coils, measured on the tangent to the base circle, as for instance *EH*, being constant and equal to the circumference.

Considering the curve as traced by the rolling of the ruler: the point of contact, for instance *A*, is the instantaneous centre (**79, 80**); therefore *AP* is normal to the curve at *P*, and, in general, the normal at any point of the involute is tangent to the base circle, and *vice versa*.

If the ruler continue to roll in the direction of the arrow, it is clear that after *P* reaches *O*, a new branch will be formed as shown by the dotted line; the two branches being tangent

to each other, and to the radius *CO* at its extremity. The method of (80) may be applied also to the involute, which is obviously tangent to arcs described about *A*, *B*, *D*, etc., as centres, with radii *AP*, *BE*, *DF*, and so on ; by subdividing the base circle more closely,

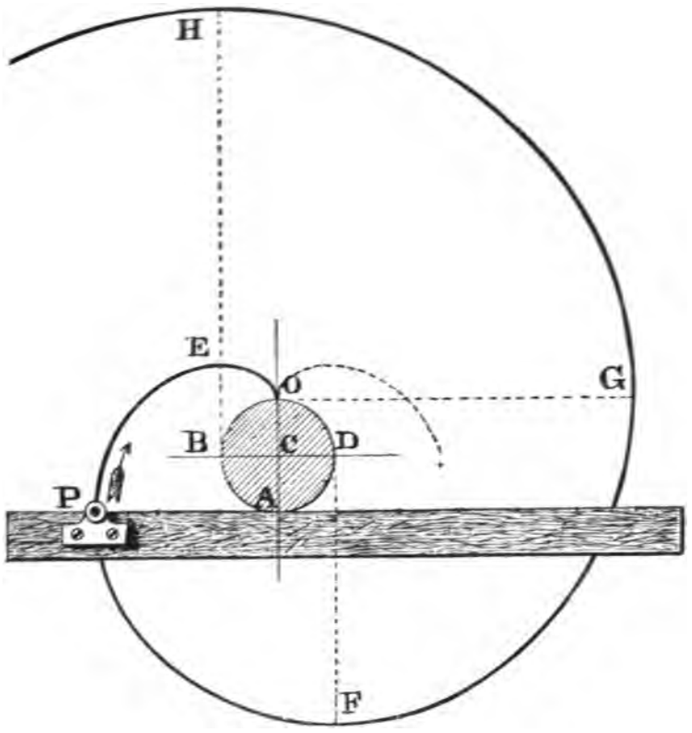


FIG. 58.

the curve may in this manner be very accurately mapped out, without locating any points upon it.

THE EPITROCHOID.

88. Although the term epitrochoidal is used in a general sense, including all rolled curves, yet custom sanctions also a special sense ; and the curve traced by the rolling of one circle upon another, when the marking point is not situated upon the circumference, is the one ordinarily meant when "*the epitrochoid*" is simply mentioned.

In Fig. 59, if the circle whose centre is *C*, roll upon the circle whose centre is *G*, carrying a marking point *P* situated without the circumference, it describes the looped curve *PLE*, called the *curtate epitrochoid.* If the tracing point be situated within the circumference as at *V*, the resulting waved curve *VWX* is called the *prolate* epitrochoid. Both may be drawn by the method of tangent arcs. Since, as in the preceding cases, the rolling circle measures itself off upon the base circle, the position of the generating radius can always be found as in the construction of the epicycloid, and, its length being constant, points

on the curve are readily determined. Also, the instantaneous radius being always normal to the epitrochoid, the tangent at any point can be drawn with the same facility. For example, let it be required to draw the tangent at L; with a radius equal to CP, describe about L an arc cutting the path of the centre C in the point R, and draw RG, cutting the base circle in a': then $a'R$ is the contact radius, RL is the generating radius, the instantaneous radius $a'L$ is the normal, and a perpendicular to it is the required tangent.

If the circle which carries the marking point rolls on the inside of the base circle, the resulting curve is called, by way of distinction, an *internal* epitrochoid; if it rolls upon its tangent, the curve is called simply the *trochoid;* but as the only modifications in the above process are those due to the form of the base line, no further explanation is necessary.

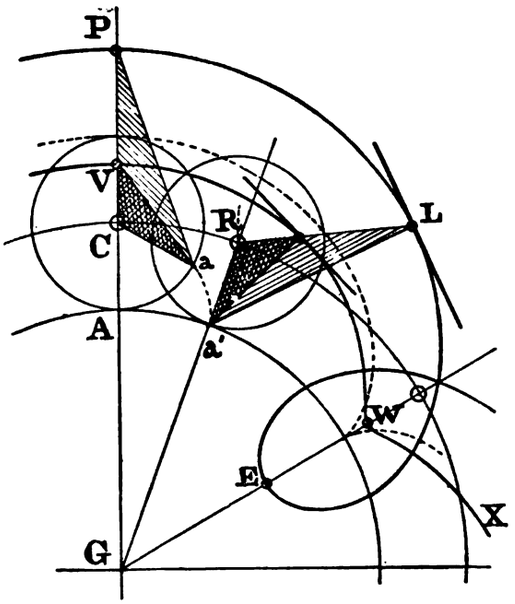


FIG. 59.

SPIRALS.

89. A Spiral is a plane curve traced by a marking point moving along a right line, while at the same time the right line revolves about one of its points as a fixed centre.

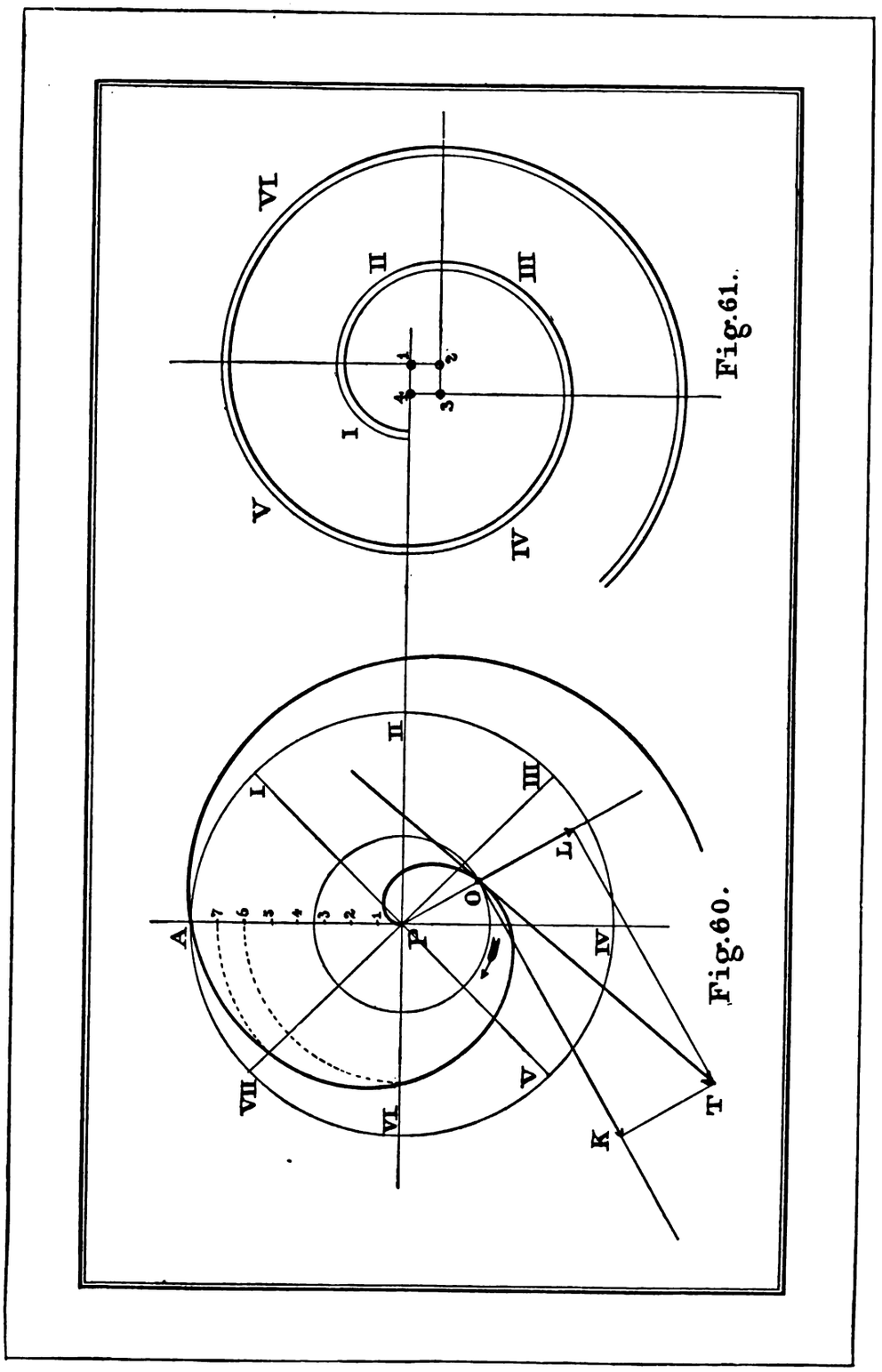
This fixed centre is called the *pole*, and a right line drawn from it to any point of the curve is called a *radiant*, or *radius vector*. Supposing the angular velocity of the revolution to be uniform, the linear velocity of the marking point along the radius vector may be governed by any law at pleasure, and thus an infinite variety of spirals may be produced.

Some of these may also be otherwise generated, as already shown in the case of the involute of the circle, in which the tracing point moves uniformly along the tangent, while the tangent revolves uniformly about the centre; but the definition first given is perfectly general, and includes them all.

90. The Archimedean Spiral.—The radius vector revolving uniformly, let the tracing point travel along it with uniform velocity. The resulting curve is the well-known spiral of Archimedes, also called the *equable spiral*, because the rate of expansion is constant, so that the distance between any two consecutive coils, measured on a radiant, is the same.

If this distance or rate of expansion be given: With it as radius, describe a circle about the pole P, Fig. 60, and divide its circumference into any number of equal parts by radial lines; divide the given distance PA into the same number of equal parts, and set out from the pole P, upon consecutive radii, as I, II, III, IV, distances equal to one, two, three, etc., of these subdivisions: the spiral is then drawn through the points thus determined.

If any two radiants and their included angle be given: Divide the included angle and the difference between the radiants into the same number of equal parts; then set off on the


VI
II
III
I
V
IV
1
2
4
3
Fig.61.
II
I
III
L
A
7
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5
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3
2
1
P
O
IV
VII
V
VI
K
T
Fig.60.

first dividing radial line a distance equal to the least radiant plus one of the subdivisions of the difference, and so on; each radiant being greater than the preceding by an amount equal to one of these subdivisions.

To draw a tangent at any point, as *O:* Drawing a circle about *P* through *O*, and rectifying a convenient fraction thereof as in (**56**), the length of the circumference may be found; and the radial travel per revolution, or rate of expansion, is known. Then, the arrow indicating the direction of the revolution, set off on the radiant *OP* a distance *OL*, and on a perpendicular to it a distance *OK*, making *OK* : *OL* :: circumference through *O* : rate of expansion. Complete the parallelogram, and the diagonal *OT* is the required tangent.

91. Pseudo-spiral.—The above spiral is sometimes used in forming the outlines of cams, in mechanical movements, and for such purposes it must be accurately laid out. It is also the form assumed by a coiled spring such as the mainspring of a watch or clock. But for the purpose of representing such a spring, it is quite needless to make so laborious a construction; an approximation to the true curve is easily drawn as shown in Fig. 61. The sides of the small square being produced, limit the quadrants I, II, III, IV, of which the centres are 1, 2, 3, 4; then the same centres are again used in order, 1 for quadrant V, 2 for VI, and so on: thus the distance between the successive coils is equal to the perimeter of the original square. A still closer approximation may be made by using a hexagon, or an octagon, in like manner. It is obvious that this more nearly represents the involute of the circle than the true equable spiral; but for the purpose mentioned the curve would not in fact extend very near to the pole, in the mechanism itself; and the accuracy of this method is amply sufficient for making the drawings of such springs.

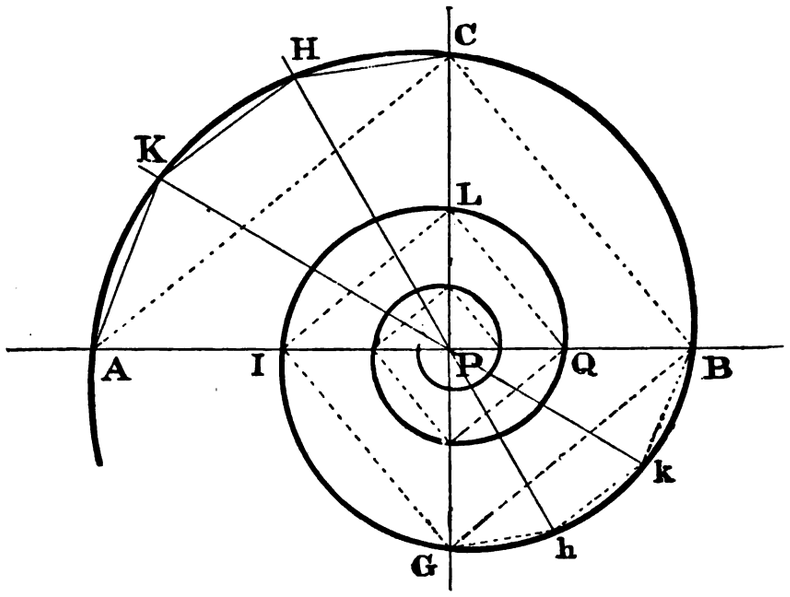

FIG. 62.

92. The Logarithmic Spiral.—In this curve the successive radiants which include equal angles form a series in *geometrical* progression, each being greater or less than the preceding in

a certain constant *ratio:* in the Archimedean spiral such radiants form a series in *arithmetical* progression, each being greater or less than the preceding by a constant *difference.* From the above definition it follows that the radiant which bisects the angle between two others is a mean proportional between them. Thus in Fig. 62, if the angles *APK, KPH, HPC* are equal, we shall have

$$AP : PK :: PK : PH,$$

$$PK : PH :: PH : PC, \text{ and so on.}$$

Had the radiants *AP, PH* and their included angle, then, been given, the intermediate point *K* would have been found by bisecting the angle *APH*, and setting off *PK*, a mean proportional between the two given radiants. Had a *diameter*, as *AB*, and the pole *P*, been given, the process would have been the same—this angle of 180° is bisected by *PC* perpendicular to *AB*, and *PC* is a mean proportional between the segments *AP, PB* of the diameter.

93. *To find the mean proportional between two given lines:* Set off from any point *P* on any right line a distance *PA* in one direction equal to one of the lines, and in the opposite direction a distance *PB* equal to the other (Fig. 63). Upon *AB* as a diameter describe a semicircle, intersecting at *C* a perpendicular to *AB* at *P*: then *PC* is the mean proportional required.

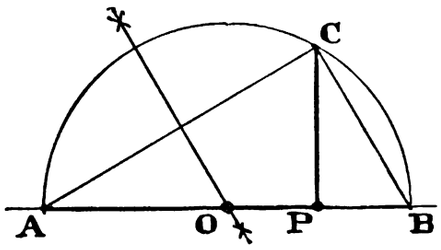

FIG. 63.

To find a third proportional to two given lines: In Fig. 63 let *AP* be one of the given lines, and *PC*, perpendicular to it, the other. Draw *AC* and bisect it by a perpendicular cutting *AP* in *O*, about which point as a centre describe a semicircle through *A* and *C*: this will cut *AP* produced in a point *B*, and *PB* is the third proportional required; for by this construction we have $AP : PC :: PC : PB$.

This last construction is often useful in extending the spiral; thus, had the curve *ACB* in Fig. 62 been determined, it is clear that *PG*, on the prolongation of *CP*, must be such a third proportional to *CP* and *PB*.

94. The length of *PG* may be otherwise determined; for since when *G* lies on the spiral we must have $AP : PC :: PB : PG$, the triangles *APC, BPG* will be similar, whence *BG* must be parallel to *AC*. So also *GI* is parallel to *CB*, *IL* to *BG*, *LQ* to *GI*, and so on.

This principle is capable of more extended application; for producing the radiants *KP, HP* to cut the spiral in *k, h*, it will be apparent that the chords *KH, kh* are parallel; so also *Bk* is parallel to *AK*, *hG* to *HC*, and so on.

95. Another Method of setting off divisions in geometrical progression is shown in Fig. 64. Draw the two lines *OM, ON*, including any convenient angle, and also *AB*, cutting them both. About *O* describe the arc *AC*, and draw *CD* parallel to *AB*; then about *O* describe the arc *DE*, and draw *EF* also parallel to *AB*; similarly, make $OK = OB$, draw *KL* parallel to *AB*, and so on as far as may be desired in each direction.

If now the distances from *O* to the points of division on either line be set out from the pole, on successive radiants including equal angles, the curve thus determined will be a logarithmic spiral.

This construction may be also adapted to any special case in which two radiants and their included angle are given. Thus, had *OA*, *OB* been made equal to those radiants, the lengths of others would be found as above; but in constructing the curve, care must be taken that the angles between them are made equal to the given angle.

MECHANICAL METHODS OF PLOTTING CURVES.

96. Mention has already been made of the use of a slip of paper for locating points upon the ellipse (**62**). Analogous expedients are often available in other cases, enabling the draughtsman to work at once more neatly and more rapidly. Thus, if the divisions determined as in Fig. 64 be set off on the radial edge of the strip of paper shown in Fig. 65, it is not necessary even to draw the radiants of the logarithmic spiral; a circle is described about the pole, and a fine sewing-needle, passed through the corresponding point *O* of the paper strip, is fixed in the drawing-board at the centre of the circle, whose circumference is first subdivided. Then swinging the strip round, setting its edge by each point of division in order, the proper point of the spiral is marked with a finely sharpened pencil. By making the divisions of the radial edge equal, the Archimedean spiral can be laid out with the same facility.

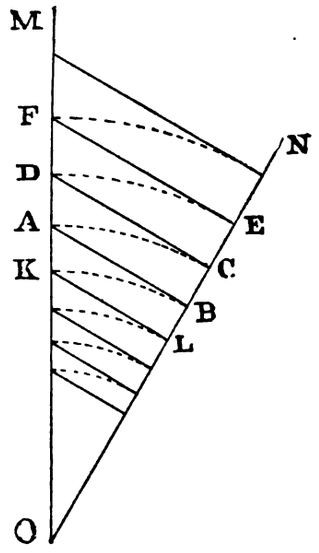

FIG. 64.

97. In Fig. 66, the lower edge of the paper strip is tangent to the circumference of the circle, and the subdivisions upon it are equal in length to the corresponding subdivisions of that circumference. Turning this as before about a needle fixed at the centre *O*, setting the radial edge *OR* by the successive points on the circumference, and marking with a fine pencil-point the corresponding divisions of the lower edge (counting from zero to the *left* when the rotation is in the direction of the arrow), the curve

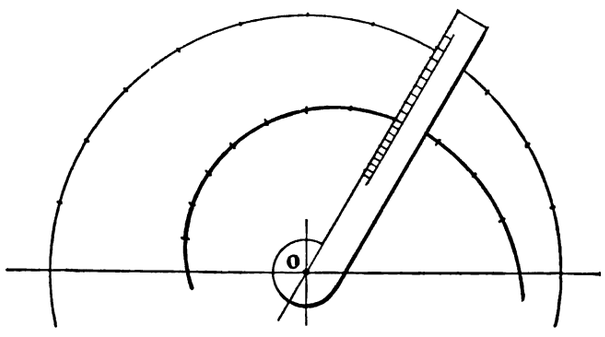

FIG. 65.

thus determined is the involute of the circle *ABC*. By counting from zero to the *right*, the direction of the rotation being unchanged, points are determined in the curve *ADE*, the *companion to the involute*. Of these two curves, the former is traced by unwinding an inexten-

sible fine thread from a *fixed* cylinder; the latter by unwinding it from a cylinder which turns upon its axis so that the thread is always tangent to the circumference at the same point.

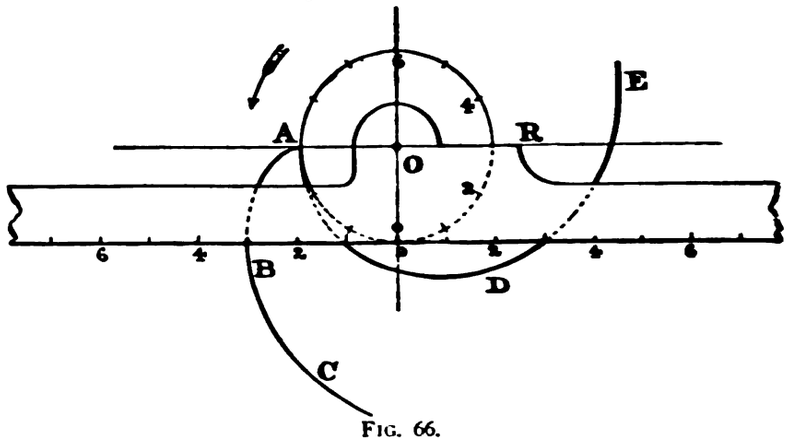

FIG. 66.

But the above simple device shows that they may also be defined as the paths of points travelling uniformly along a right line, while the line itself revolves uniformly about a fixed point not situated upon that line.

These, however, are special cases, the travel along the line during each revolution being equal to the circumference of the circle to which the line is tangent. But it need not be; and by means of different graduations of the paper strip it is easy to plot, without drawing a single construction line except the divided circumference, this whole class of spirals, of which the involute and its companion are the most conspicuous representatives.

98. The path of any point on the connecting-rod of a direct-acting engine may be plotted as easily as the ellipse, the only difference being that one of the fixed points on the paper slip is to be kept always on the circumference of the circular path of the crank-pin. If the connecting-rod is coupled to two equal cranks, like the side rod of a locomotive, and these cranks turn in opposite directions, the middle point of the rod traces a lemniscate; which may also be easily plotted by the above method.

The piston-rod of an oscillating engine passes always through a fixed point, which may be represented by a fine sewing-needle stuck into the drawing-board: against this let the edge of a straight slip of paper be pressed, a fixed point thereon being kept on the circumference of the path of the crank-pin, and the curve described by any point on the rod can be plotted; if this circle be of infinite radius, the curve becomes the conchoid, while if the centre of oscillation be located on the circumference, it becomes the limaçon.

99. Any of these paths may be constructed at pleasure as exercises in the drawing of curves; and as a final illustration of this method of manipulation, we give in Fig. 67 three of the curves which may be plotted by means of Newton's Square.

This was devised by that renowned geometer for drawing the cissoid; of which the generating circle is that whose centre is *O* in the figure. On the vertical line through *O* a needle is fixed at *E*, the distance *OE* being equal to the diameter of the circle. Against the needle the side *BF* of the square *DBF* is kept, while the point *A*, whose distance from *B* is equal to *OE*, is kept always on the horizontal line through *O*. Then the middle point *P* of

AB traces the cissoid *PC*; a point *D*, so situated that $AD = AP$, traces the waved curve called the wizard, while the corner *B* traces the looped curve called the sprite.

It will be clear that when *P* reaches *C*, the working edge *DB* will coincide with the

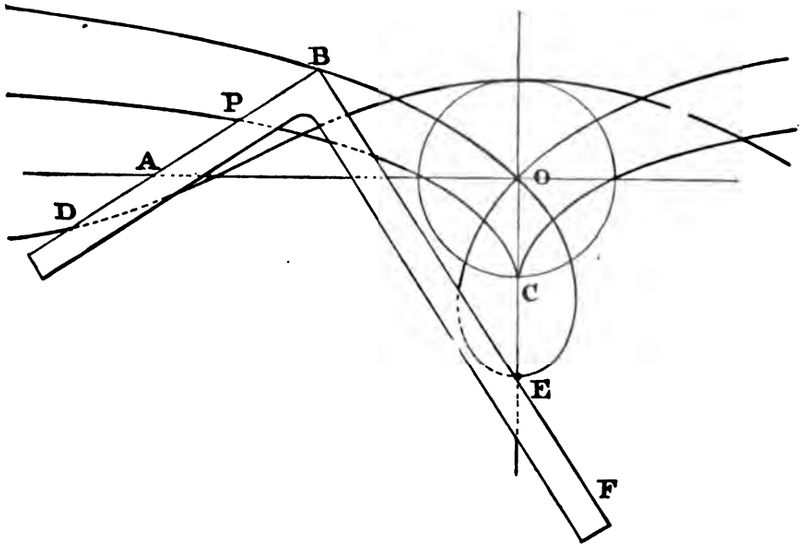

FIG. 67.

vertical line *OE*: the square must then be turned over, and the under side used for continuing the curves to the right.

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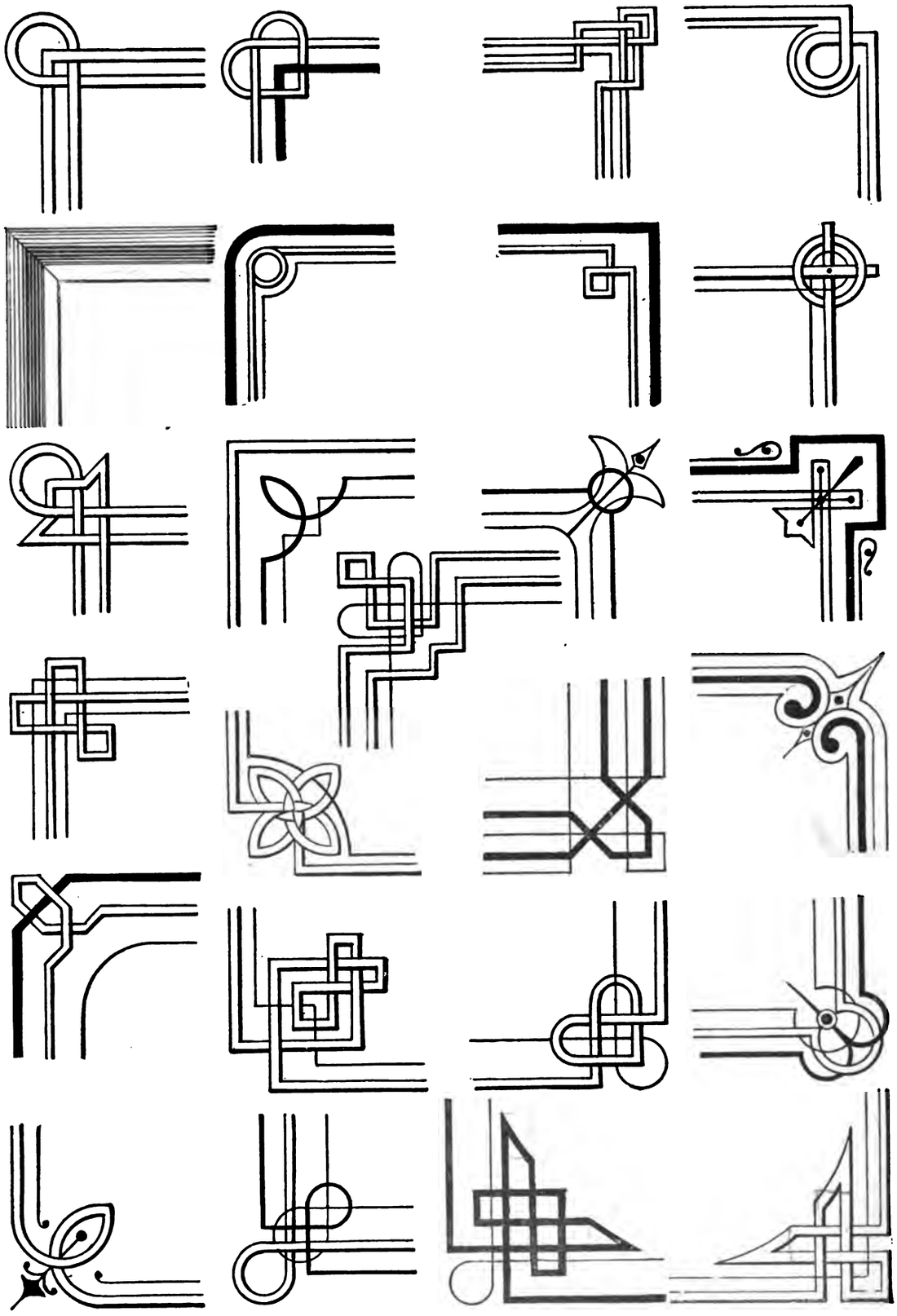
100. Before proceeding farther, we give on page 52 a number of examples of "corner-pieces," suitable for borders of a more ornate style than the simple ones heretofore employed.

From these the ambitious student may select such as suit his fancy or his estimate of his skill,—with the understanding that they are to be executed with the same care and subjected to the same criticism as any part of the exercises contained within them. With this understanding, no instructor possessed of ordinary common-sense will attempt to control his selection, except by hints and suggestions. He may and very likely will at first set his heart upon something glaringly inappropriate to the case in hand; but he will be much more readily convinced of this after he has drawn it than before. And good taste in this can no more be acquired without experience, than can perfection in the execution of the exercises themselves.



CHAPTER III.

THE PRINCIPLES OF PROJECTION.

101. Pictorial representations, such as photographs and perspective drawings, while they may give perfectly correct ideas of the form, proportions, and general appearance of the objects depicted, are of no use for constructive purposes. Parallel lines are represented by converging ones, equal lines by unequal ones, right angles by those which are obtuse or acute: so that, in general, no accurate information can be obtained by direct measurement.

Working drawings, however, are needed for the absolute guidance of the workman, who by their aid alone must be enabled to produce precisely what is intended, and that only. Such drawings, then, must exhibit the exact forms and dimensions, and also the true relations of the various parts, in a manner both direct and unmistakable.

The difference between a perspective and a working drawing is sometimes expressed by saying that the former shows things as they *seem*, the latter as they *are:* but the precise nature of this difference may be explained as follows:

102. Suppose the eye (regarded as a single point) to be placed in a given position in front of a plate of glass, and to be looking perpendicularly against its surface, which is called the **picture plane.** Any point of an object beyond the glass is visible, because light is reflected (or **projected**) from that point to the eye in a right line, called a **visual ray.** And the point in which that ray pierces the picture plane is the representation, or **projection,** of the point from which it came. If a sufficient number of such points be found, the outlines of any object may be fully determined, and the drawing thus made will present to the eye, if placed in the position originally assigned to it, the same appearance as the actual contour of the object itself.

103. When the eye is placed at a *finite* distance from the picture plane, the drawing is said to be in **perspective.** In this case the visual rays converge, and but one of them can coincide with the axis of vision, which is perpendicular to the plane. Nevertheless, the eye, without straining and without turning, can receive distinct impressions from all visual rays embraced in a cone whose angle at the vertex is about sixty degrees: the picture plane cuts from this cone a circle, within which the drawing should be included.

104. Other things being equal, the visual rays will converge the less rapidly the farther the eye is removed from the picture plane. If the eye be placed at an *infinite* distance, the rays will become parallel to each other and to the axis of vision, which is still supposed to be perpendicular to the plane. In these circumstances the drawing is called an **orthographic projection,** the visual rays are usually designated as **projecting lines,** and the picture plane is called the **plane of projection.** It will readily be seen that a plane may be so interposed as to cut the parallel projecting lines at any other angle; that is to say, the eye, although infinitely remote, may not be directed perpendicularly toward the plane: the drawing is then

called an **oblique projection,** and in some cases is of great utility and convenience. The former arrangement, however, is much more extensively used, and thorough familiarity with it is necessary to an intelligent use of the latter. For the present, then, it will be understood that in speaking of **projections** reference is made only to those constructed on the orthographic system.

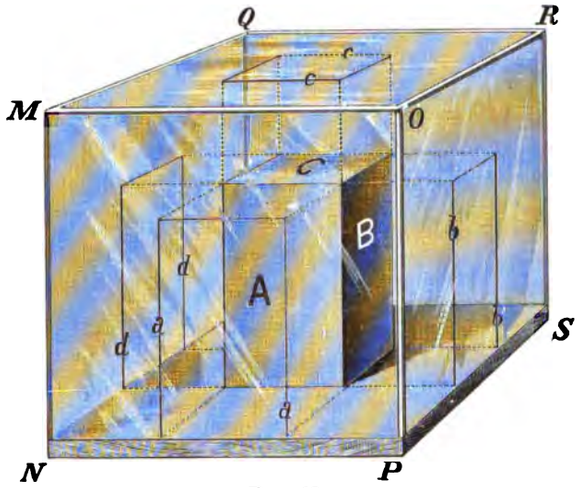


FIG. 68.

105. Fig. 68 is a perspective drawing of a rectangular prism, placed within a case formed of plates of glass, upon which the projections of the object are made in the manner above explained: thus, *aa* is the projection of the front face *A*, *bb* is that of the side face *B*, and *cc* is that of the upper face *C*. The left side face of the prism is not visible, but its projection upon the left side of the glass case is shown at *dd*.

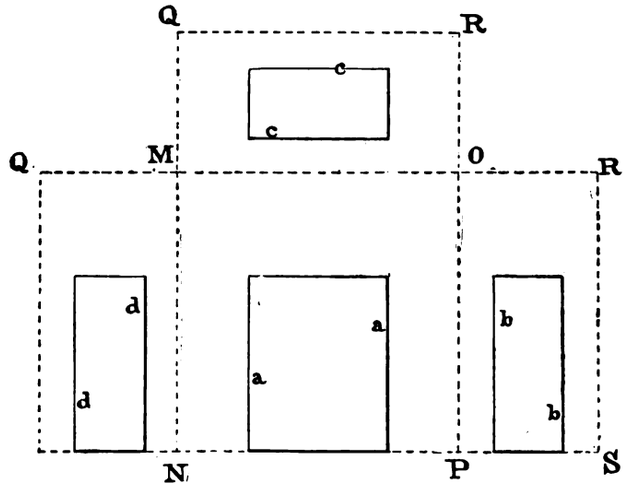


FIG. 69.

Now suppose the sides and the top of the case to turn outward, about the lines *MN*, *OP*, and *MO*, until they coincide with the front plate *NO*. The four projections will then be arranged as shown in Fig. 69, the dotted lines representing the sides of the glass case. Re-

garding *A* as the front of the object, the projection *a* is commonly called a **front view**, *b* and *d* are called **side views**, and *c* is called a **top view**; although in the case of an object lying upon its longest side *a* may also be properly called a **side view**, *b* and *d* being then spoken of as **end views**. These three projections, which are made upon vertical planes, are also, particularly in relation to architectural subjects, designated as **elevations**; *c* being in that case called a **plan view**, or simply a **plan**.

106. In reference to the arrangement, it is to be specially noted that *b*, which is a view of the object *from the right*, is placed **at the right** of the front view *a*, while *d*, a view *from the left*, is placed **at the left**. This may seem of small consequence, and in fact it is so in representing so simple an object; but suppose *A* to be for example a side view of a locomotive heading to the right, and it will readily be seen that the view of the headlight and the cow-catcher, which is only to be had by looking at the engine from the right, is most naturally and appropriately placed at the right side of the front view; as the parts seen in that end view are thus brought nearer to their representations in the first one. It may be said that without any reference to planes of projection, this arrangement of the views is that which would be suggested by simple common-sense to any one who, provided with paper and pencil, should sketch an object as he sees it, first from directly in front, and then from the right or the left, as the case may be.

107. In regard to the plan, or top view, however, there is this to be said, that no ambiguity or doubt can arise if it be placed below the elevation, or front view. Because it is invariably a view of the object *as seen from above.* Under no circumstances should a projection be made which involves the idea of the eye being placed beneath the object and looking upward,—with the possible exception of a design for a frescoed ceiling. Such projections *are* occasionally made, and are even recommended by some; but that does not lessen the force of the objection, that they are difficult to read because they represent things as seen from a most unusual direction. It is certainly often necessary to know the appearance of the lower end of a part of a machine, for example, which is to be placed in a vertical position. But in order to find it out, one does not hold the object over his head and look upward: the natural proceeding is either to turn it upside down, or to lay it on its side and look at it horizontally; and the same course may be adopted in making the projections,—of which more hereafter.

Consequently, a top view may be placed **either above or below** the elevation, as may appear most convenient or suitable; in the case of the locomotive, for instance, it is easy to see that the top view, being of nearly uniform breadth, will present a more satisfactory appearance if placed under the side view, in which usually the rail is represented, than if put so far above as to be well clear of the smoke-stack, sand-box, cab, and steam-drum, which form a very irregular contour.

108. In Fig. 70, *A*, *B*, and *C* are the projections of the three faces of the prism correspondingly lettered in Fig. 68. It is to be noted that each projection exhibits only two dimensions; thus the front view gives the height and the breadth, the side view gives the height and the thickness, the top view gives the breadth and the thickness. Also, that the height *ad* is the same in *A* and *B*, the breadth *ab* is the same in *A* and *C*, while the thickness *ac* is the same in *B* and *C*.

It will also be observed that while the perspective representation conveys in one view a correct and complete idea of the form of the object, no one, nor yet either two, of the projections are sufficient to do this. Were *A* and *B* only given, it could not be told whether any or all of the vertical edges were square or rounded off; and if *A* and *C* were the only views, the top or the bottom, or both, might be either plane, or curved transversely; but the three together define the form completely.

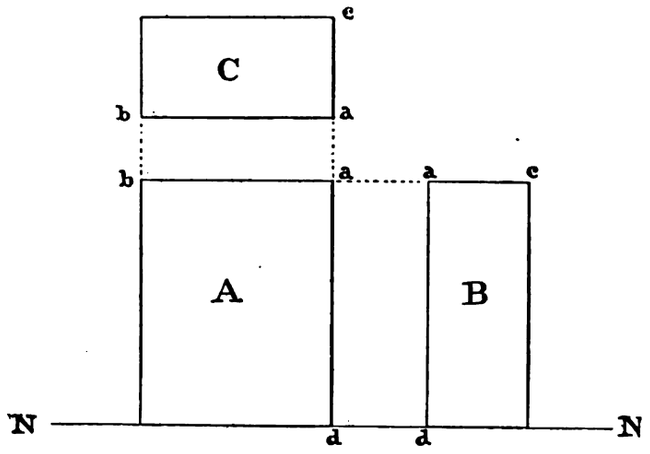


FIG. 70.

109. Again, it will be noted that each of the projections represents a face of the prism in its true form and size. A very little study of Fig. 68 will show that this is because the planes of projection are parallel to those faces; the projection of a line is made by connecting the projections of all its points, from which it follows that if a line be parallel to the plane of projection, it will be represented on that plane by a similar and equal line. For example, had the object been an upright cylinder, the projections *a*, *b*, and *d* would still have been rectangles, but *c* would have been a circle. The position of the object is of course arbitrary; thus, the prism might have been turned part way round, or placed upon an edge or a corner. But the position actually shown is the simplest one, and the one which would naturally be selected for making a **working drawing**, which Fig. 70 is properly called, since by its aid the object represented can be made by a workman, who takes his measurements directly from the projections.

The prism is shown as resting upon the horizontal plane *NS*, forming the bottom of the glass case. This in Fig. 70 is indicated by the horizontal line *NN*, called a **base line**; which, though not essential, is in many cases introduced with excellent effect, for it at once shows unmistakably that the view beneath which it appears is an elevation, and not a plan.

110. This position of the prism, which may be also described as that in which its lines and faces are parallel and perpendicular to the paper in each of the projections shown in Figs. 69 and 70, has been selected not only by reason of its simplicity, but because, as will be shown presently, it is the starting point from which we set out in determining the projections of the same object in oblique positions. In those positions the projections, though still orthographic, may not show the lines and angles in their true dimensions; and in order to

construct them correctly, it is necessary to possess the information conveyed by Fig. 70, the construction of which is indeed an essential preliminary.

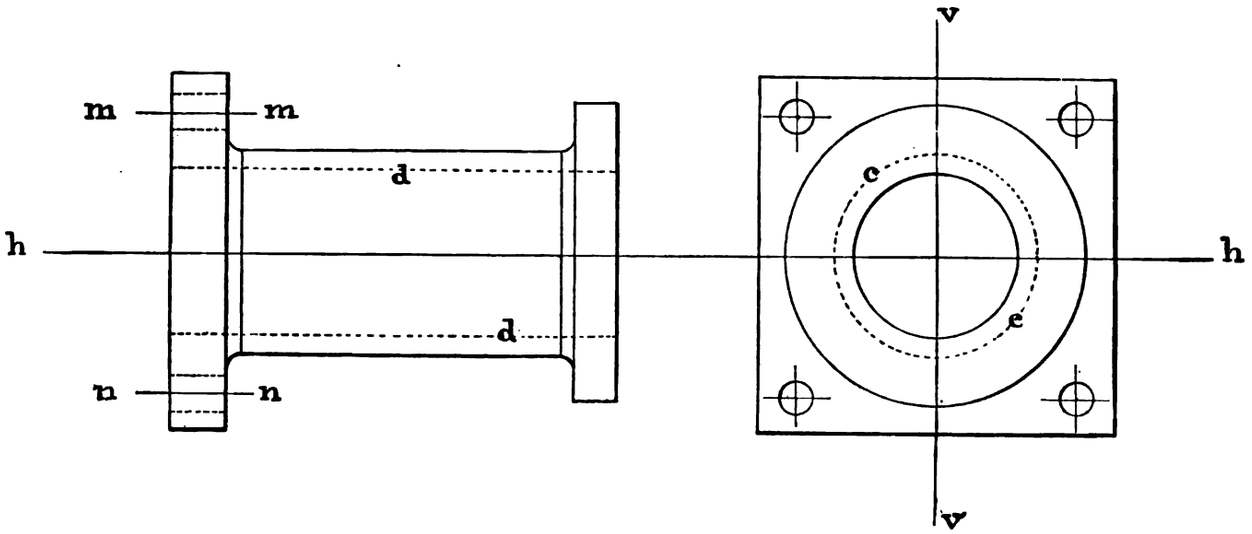


FIG. 71.

Before going on to discuss those more complicated matters, however, it may be remarked that in a working drawing the most simple and direct representation is always the best; so that the principles already explained are sufficient for practical application, to very good and useful purpose, in the delineation of minor mechanical details: of which accordingly we introduce one or two examples.

111. Fig. 71 represents a horizontal cylinder, having at one end a circular flange, and at the other a larger square one, in which are four bolt-holes.

In this case two views are sufficient, as a top view would be identical with the side view. The circular flange on the right-hand end being the smaller, a view from that end defines the whole, as the square one at the left is visible beyond, as also are the bolt-holes. Parts not visible are indicated by dotted lines, as for example *d* in the front view and *c* in the end view, and the outlines of the bolt-holes in the former.

In Fig. 70 it will be noticed that the projecting lines *aa*, *bb* are represented, in dotted lines, for the purpose of indicating the relations between the different projections. In illustrative diagrams, this is necessary in order to aid the reader in following the explanations. But when the subject is mastered they are no longer required, and in working plans are very rarely introduced, the practised eye being able to *read* the drawings, and compare one view with the others, without such assistance.

112. But when, as in Fig. 71, the object is symmetrical about an axis, and especially if it be a surface of revolution, it is customary to connect such views as these by a continuous **centre-line**, as *hh* in the figure; and in the end view to locate the centre by a transverse centre-line, *vv*. Similarly, the centres of the bolt-holes are marked in the end view by short vertical and horizontal centre-lines, corresponding horizontal ones, *mm*, *nn*, being drawn in the side view. These are of the first importance, since it is by measurements from these lines

that the mechanic lays out his work, and they should never be omitted. Being imaginary lines, they should be drawn as fine as possible, and should **never terminate in a bounding line** of the object represented, or of any part of it. In drawings of machinery, if different colors are used, it is customary to draw them in red.

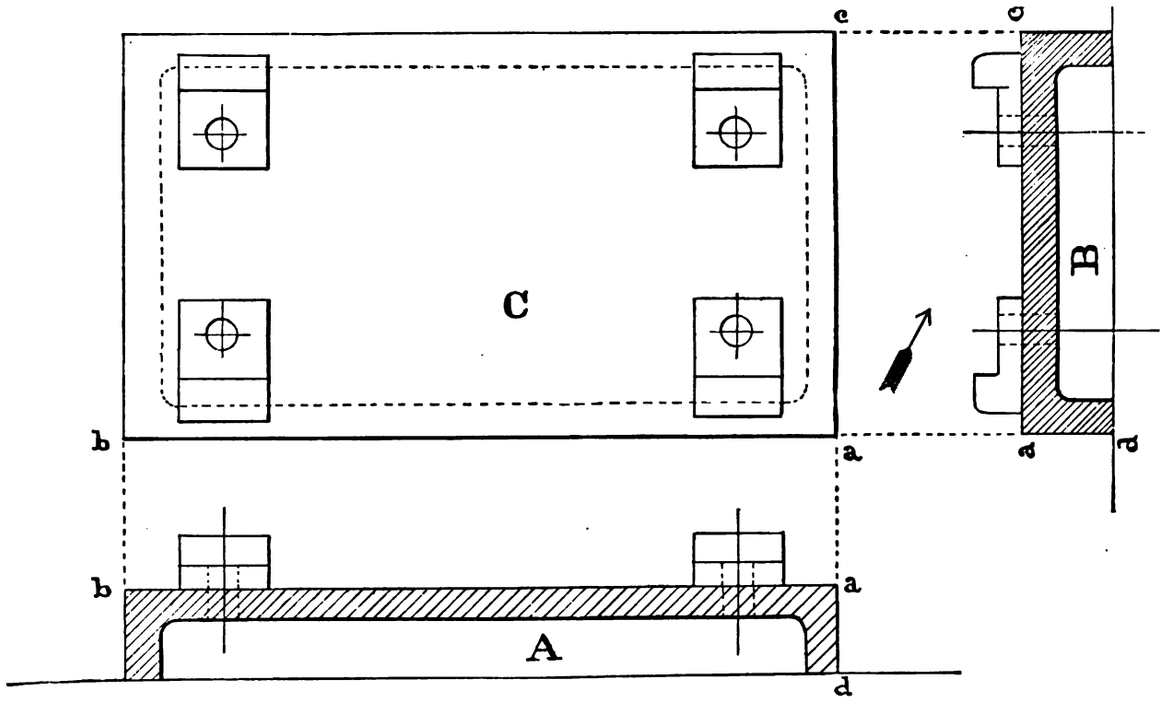


FIG. 72.

113. Fig. 72 represents a small bed-plate, with four facing-strips and lugs on its upper face. Though not absolutely necessary in so simple a subject, the views *A* and *B* are shown in section, as showing more distinctly the box-like form of the bed-plate: such views are commonly called **sectional elevations.**

In this instance three views are necessary; and the figure shows an arrangement of them which is frequently adopted in order to economize space. The breadth being considerable as compared to the height, it is clear that if, as in Fig. 70, *B* had been placed at the right of *A*, the three views would have occupied more space than they now do. But when it is placed at the right of the plan, as in the figure, it will be at once seen that *C* is as correctly a top view of *B* as it is of *A*.

When this arrangement is adopted, the fact that *B is* an elevation should be emphasized, by the proper use of shadow-lines according to the direction of the light shown by the arrow, as well as by the manner in which the dimensions, if any, are figured; so that it shall always be looked at as it should be, that is, by turning the paper a quarter round to the right, thus changing horizontal to vertical, and *vice versa*. If as in this example the subject is such as to render the introduction of a base-line appropriate, it forms a most effective aid to the correct reading of the drawing.

114. Figs. 70 and 72 are similarly lettered, and by comparing them a clearer idea may

perhaps be gained of the correspondence of dimensions in each two of the three projections. It is now time to impress upon the reader that advantage should be taken of this correspondence in constructing the drawings. Thus, for instance, the lines *ba* in the top view *C*, and *ad* in the end view *B*, should be drawn at one setting of the T-square; also *ac* in the top view and *ad* in the front view *A*, should be drawn at one setting of the triangle, and so on.

This is in accordance with the principle previously enunciated, that as much as may be should always be done with one adjustment of an instrument. But a great additional advantage of thus **setting up the different views simultaneously** as far as possible, lies in the fact that errors, to which even the most experienced are liable, are thus more likely to be at once detected than if each view were constructed separately. This is of special importance in planning, aside from the more perfect conception of the proposed structure gained by aid of the different views; but the saving in time is also considerable, and the habit should be formed at the start and always retained.

115. And so should the habit of **working from centre-lines,** which in general should be among the first lines pencilled in. For example, the lines *hh* and *vv* should be first laid down in drawing Fig. 71; equal distances above and below *hh* are laid off to locate the centre-lines *mm* and *nn* of the bolt-holes in the left-hand view, and the half diameter of each bolt-hole is set off by the scale on each side of its own centre-line; nothing could be less workmanlike, or more likely to lead to errors sooner or later, than to construct such drawings by measuring from the edge of a flange to the side of a bolt-hole, and from the side of one hole to the side of another. In short, the draughtsman should lay out his work on paper very much as the mechanic lays out his on metal.

116. In Fig. 73 are given three views of a piece formed by milling the upper part of a vertical cylinder into the form of a hexagonal prism. The top view is first made by drawing a circle of a diameter equal to that of the cylinder, and inscribing within it a hexagon. The points *a*, *b*, *c*, etc., represent the vertical edges of the prism, which in accordance with what precedes, will in the front view appear perpendicularly under these points, and be seen in their true lengths, as *al*, *ck*, etc. The edges *al*, *dg* coincide with the visible outlines of the cylinder, *lp*, *gh*, which also are represented in the top view by the points *a*, *d*. The upper front edge *bc* being horizontal, and parallel to the paper in the front view, appears of its true length in both the views *A* and *C*. But *ab*, *cd*, though horizontal and consequently seen in their true length in *C*, are inclined to the paper in the front view, where they appear what is technically called **foreshortened,** that is, of less than their actual length.

A third projection of so simple a thing is not necessary; but if as an exercise it be required to make it, we have now all the data: the altitudes will be the same in *B* as in *A*, the diameter x of the cylindrical part is also of course the same, and the "short diameter" y of the hexagonal part is given in *C*, and will be equal to that in the new view; to which it is transferred by setting off $\frac{1}{2}y$ on each side of the vertical centre-line.

117. Foreshortening, then, means the apparent reduction in the length of a line caused by viewing it obliquely. It was already understood that a line parallel to the paper is projected in its true length, while one perpendicular to it appears as a point. In intermediate positions it must therefore appear of intermediate lengths, and from Fig. 73 it will be clear that the amount of foreshortening depends upon the angle which the line makes with the paper, being

the greater as that angle approaches 90°. For example, the line *cd* appears shorter in the view *A*, where the angle is 60°, than in the view *B*, where it is 30°.

A little study also shows that in the former view the lines *ab* and *cd*, and in the latter the lines *cd* and *de*, are equally foreshortened, because they make equal angles with the paper.

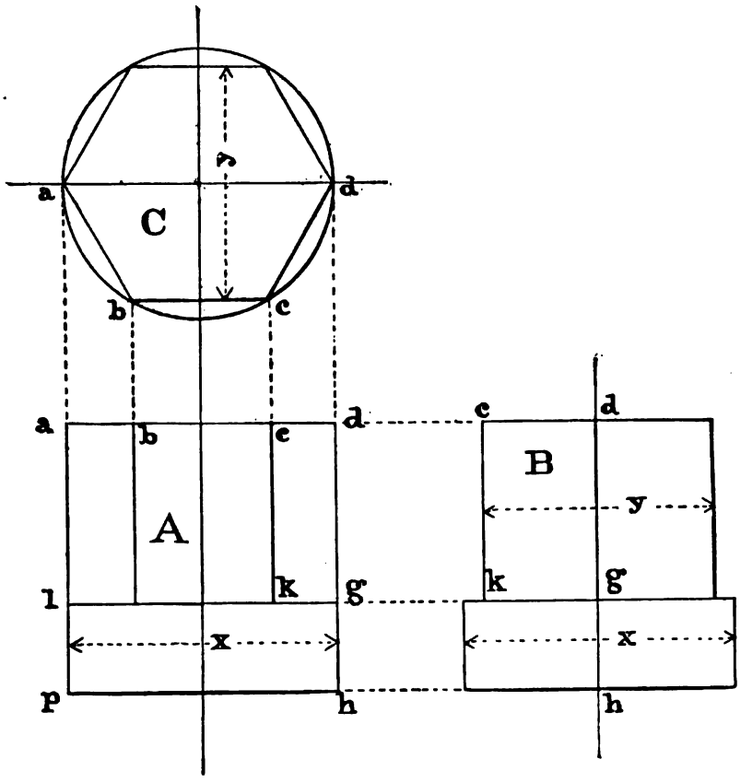


FIG. 73.

From this follows the deduction, which in subsequent operations will be found of great importance and utility, that **lines which are equal and parallel in space will appear equal and parallel in any projection**;—a fact which the student should fix in his mind so that it will stay there.

118. It will have been inferred that if two projections are sufficient to represent the object completely,—that is, so that by their aid a workman can make it and cannot make anything else,—no more are necessary. Ordinarily, two are not enough, while three are—but not by any means in all cases; and when they are not, as many more must be added as the occasion demands.

Fig. 74 represents a rectangular prism with projecting pieces upon its different faces, purposely so formed and located that they cannot, even by dotted lines, be so defined by means of the three views thus far considered, as to convey clear and unmistakable ideas of what is intended. In addition to the views *A*, *B*, and *C*, a view *D* of the left face is placed at the left side of the front view *A*. But a back view is also necessary; and it may, in conformity with the foregoing methods, be logically placed as shown at *E*. For regarding *B* for the

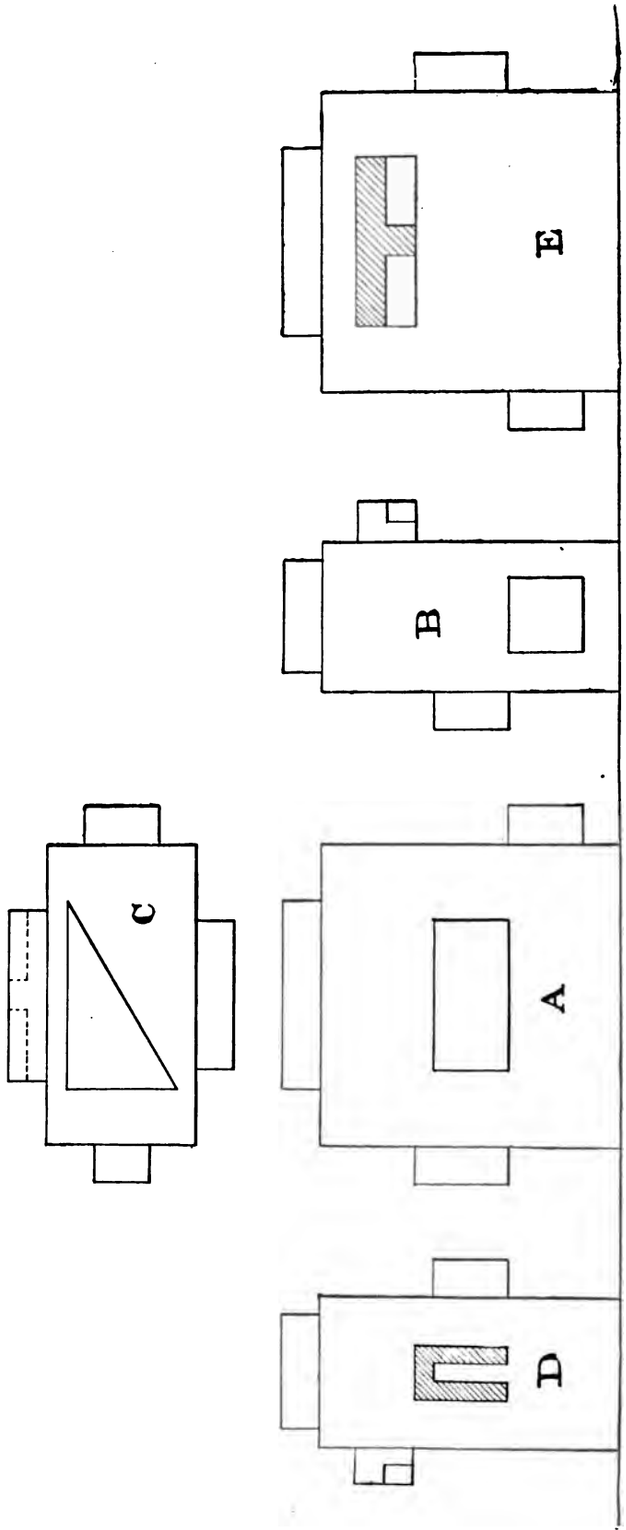


FIG. 74.

moment as a new front view, it will be clear that A will be a view of the object from the left, and E a view of it from the right.

119. Again, it sometimes happens that although a certain number of views are sufficient to define the construction, and that too without ambiguity when once they have been studied out, yet there is difficulty in reading them. If this difficulty can be lessened, and the meaning more clearly expressed, by the addition of other views, it is the draughtsman's duty to add them. We are entering upon the study of projections for a definite practical purpose, that is, the making of working drawings for workmen to use. They cannot use the drawings if they cannot read them; and if they cannot read them easily, then in a practical sense the drawings are bad in proportion to their obscurity, no matter how accurate or how perfect in execution.

CHAPTER IV.

PROJECTIONS CONTINUED.—OBJECTS IN INCLINED POSITIONS.

120. In Fig. 75 a rectangular prism is shown, as before, in its simplest position. Using a geographical illustration, A is a view from the south, D a view from the west: let it now be required to make a view from the south-west, as indicated by the arrow m. It will be readily seen that the horizontal plane on which the prism stands will be represented by a new base-line $N'N'$, perpendicular to the arrow; and that the vertical edges of the prism will be represented by lines *ad*, *be*, etc., drawn through the points *a*, *b*, etc., of the view C, parallel to the arrow: since the altitude is not affected by thus changing the point of view, these edges still appear in this new front view, A', of their true length, just as they did in the original front view A.

121. This is as though the glass case in Fig. 68 had been turned part way round *to the right*, while the prism within it retained its original position. The same result may be reached by supposing the case to remain stationary, while the prism, still standing upright on the bottom of the case, is turned *to the left* through the same angle. This is shown in Fig. 76: it needs no argument to show that the upper face of the prism will undergo no change of form or size, as seen from above, by this rotation about a vertical axis, so that the top view in this figure is simply a copy of C in Fig. 75. Also, the base-line NN remains the same, as well as the altitude of the prism, so that the front view A' is constructed by drawing the vertical edges *ad*, *be* perpendicularly over the points *a*, *b*, which represent them in the new top view, and similarly for the other edges; the heights being the same as in views A, D, of Fig. 75; and the views marked A' in Figs. 75 and 76, clearly, are identical.

122. Now let it be required to construct a view of the prism in its new position, Fig. 76, as seen from the right; or, geographically, from the east, as indicated by the arrow k. It may be, perhaps, more clearly seen how this is done, by at first adopting the arrangement of views employed in Fig. 72. The horizontal plane will be represented by a new base-line $N''N''$, perpendicular to the arrow; turning the paper round so as to make this line horizontal, it will be obvious that the vertical edges will be represented by *ad*, *be*, etc., drawn through the points *a*, *b*, etc., of the top view, parallel to the arrow k, and of the same length as in the front view A': which is in fact their true length, because they are parallel to the paper in this view also.

If this new view B'' be turned a quarter round, and placed at the right of A', it will appear as B'; which is the arrangement most frequently adopted.

123. The student should now be able without difficulty to perceive that the view B' may be at once constructed, without the use of B'', as follows: Draw in the top view a line pp, parallel to NN: this represents the edge of a vertical plane, in this instance containing the front vertical edge of the prism; as though the object had been placed in contact with the front plate of the glass case in Fig. 68. To an observer placed at the east and looking toward

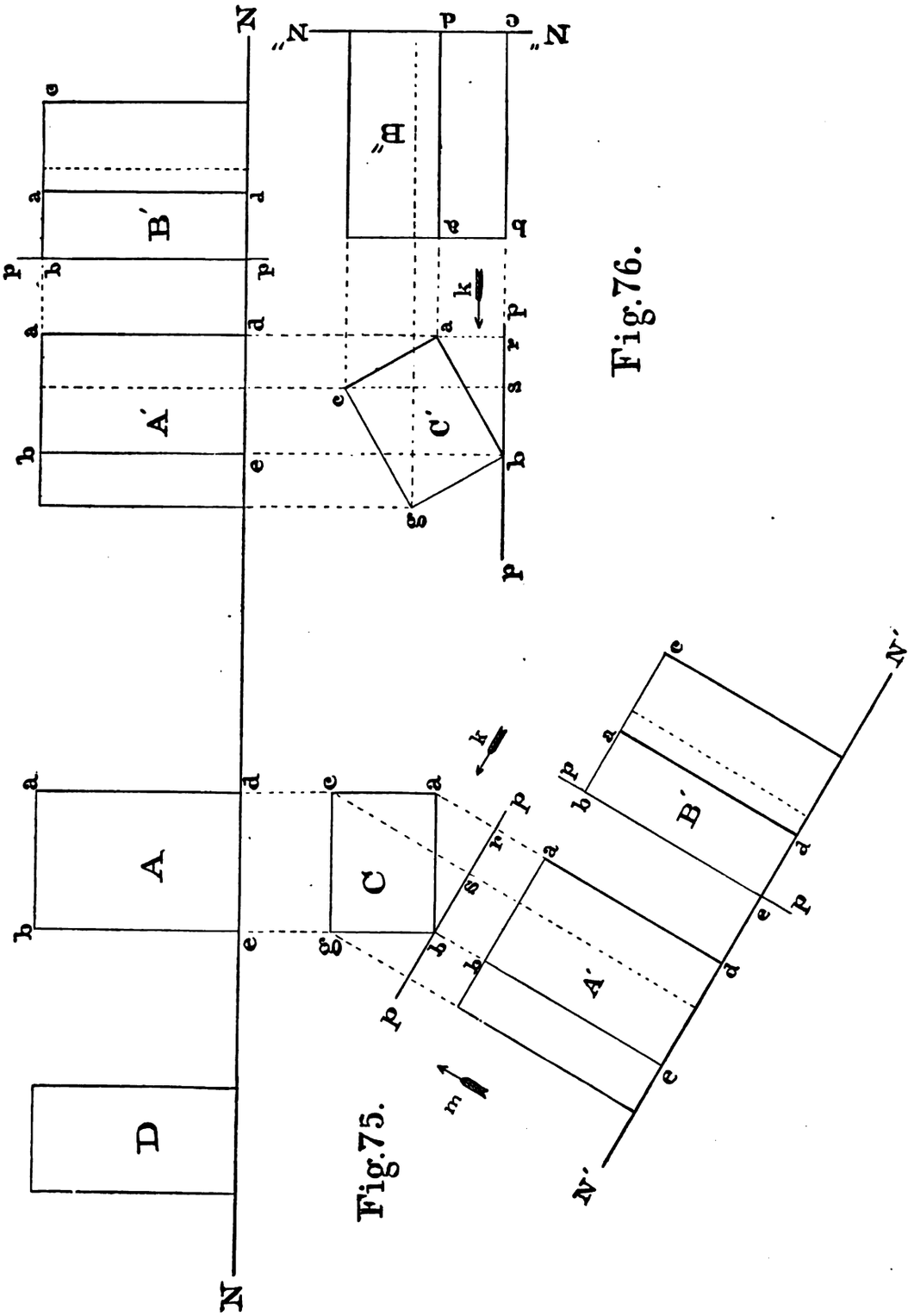


Fig.75.

Fig.76.

the west, as shown by the arrow *k*, this plane will also present its edge, and appear as the vertical line *pp* in the view *B'*. To such an observer, also, the edge represented by *b* in the top view will appear at the extreme left, and coincident with *pp*; while the edge represented by *c* will appear at the extreme right, and at a distance from *pp* equal to *cs*; to which therefore *bc* in the required view *B'* is made equal. Similarly, the perpendicular distance of the edge *ad* from the plane *pp* is *ar* in the top view; and as *ar* is seen in its true length, whether we look down upon it vertically from above, or look at it horizontally from the right of the object, this length is set off as *ba* in the new view.

124. This last mode of procedure, evidently, would be decidedly the preferable one were it desired to supplement the front view *A'* in Fig. 75, by a side view as seen from the direction indicated by the arrow *k*. This has been done in the illustration, and it is now perfectly obvious that *B'* is the same in Figs. 75 and 76. In short, the only difference between these figures consists in the fact that in the former the original view *C* is made to do double duty, being also the top view in the group *C*, *A'*, *B'*, in reading which the paper should be so held as to make the new base-line *N'N'* horizontal.

Virtually, then, in Fig. 75, and actually in Fig. 76, the original position of the object has been changed by rotation about a vertical axis, that is, one perpendicular to the paper in the top view; and it is to be noted, that not only is *that top view unchanged*, but so also are the altitudes, or *measurements parallel to the axis:* and it is by reason and by means of these two circumstances that we are enabled to construct the projections of the object in its new position.

125. Now, referring to Fig. 68, we may suppose the prism to be tilted forward or backward, rotating about the front or the back edge of its lower base, or in other words, about an axis perpendicular to the paper in the side view. In this case it will readily be seen that the *side* view of the face *B* will not be changed, nor yet the apparent *breadth* of the front face *A*, the projection of which in the new position will still be bounded by the same vertical lines *a*, *a*.

In Fig. 77, therefore, supposing *A* and *B* to be the front and side views of the same prism as in the preceding figures, we first construct *B'*, a copy of *B*; the edges *a*, *b*, *c*, *d* are still horizontal, and are seen in the new front view *A'* in their true length, and at the same distances above the new base-line *N'N'* as in the side view: so that *A'* is readily constructed from *A* and *B'* by means of the T-square and triangles only. Next suppose a vertical reference plane, *pp*, to be passed through the edge *a*: then in the top view *C'* the other edges *b*, *c*, *d* will appear at distances from *pp* respectively equal to *bt*, *cs*, *dr* in the side view *B'*.

Instead of copying the original side view *B*, we might have drawn a new base-line, *N''N''*; then looking down perpendicularly toward this new horizontal plane, as shown by the arrow *k*, the edges *a*, *b*, etc., would have appeared of their true length, which is given in *A*: and thus the top view *C''* is constructed, the process being exactly analogous to that adopted in Fig. 75. It is hardly necessary to point out that this result is precisely the same as if the top view *C'* had been laid out under the side view *B'*, by projecting the edges *a*, *b*, etc., vertically downward, and measuring their lengths from *A'*.

126. Similarly, we may imagine the prism in Fig. 68 to be inclined to the right or the left, by turning about an axis perpendicular to the front plate of the glass case. The *front*

view will then evidently undergo no change in form or size, nor will the *thickness*, as seen in the side and top views. The construction of the drawing in this new position is so similar to

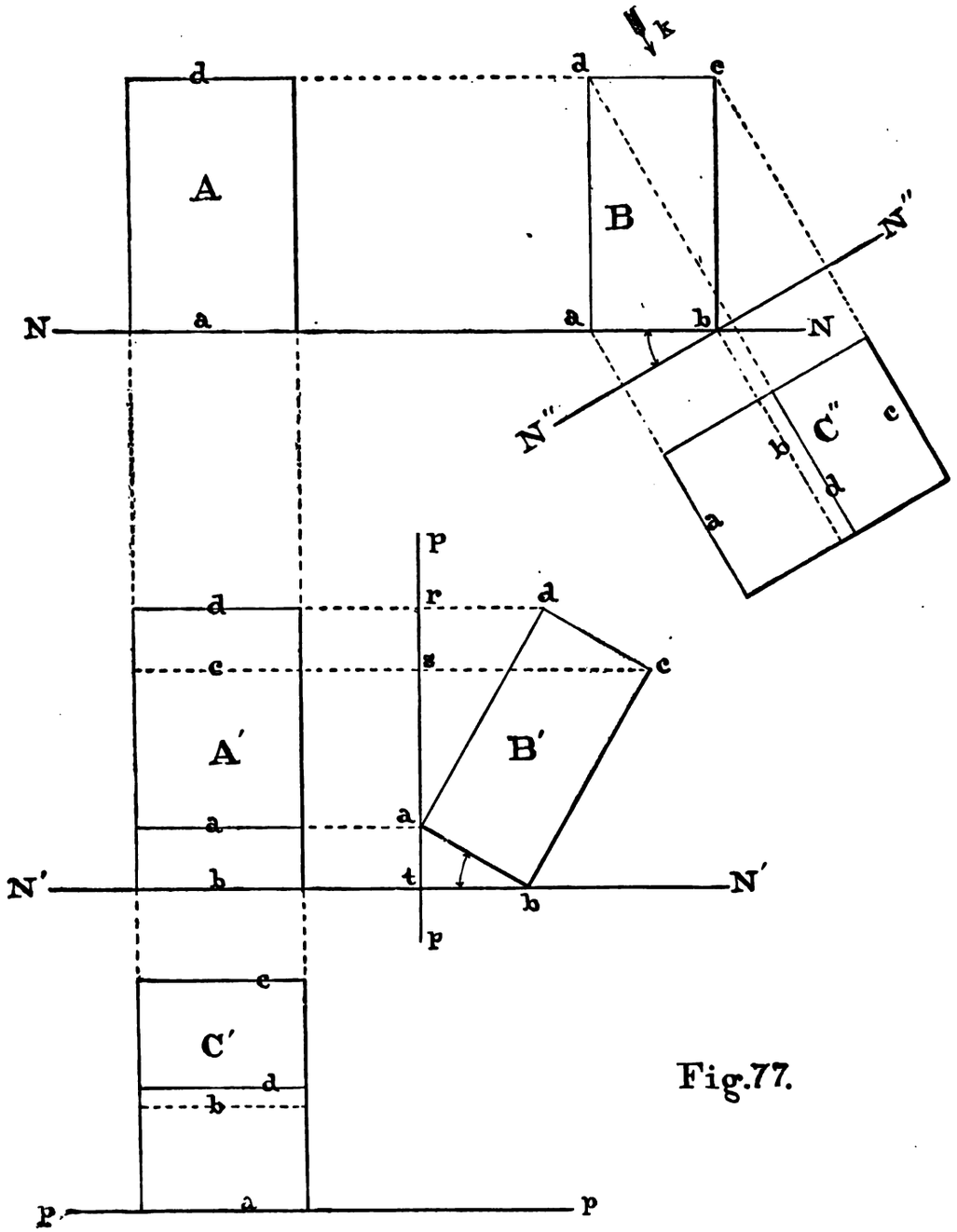


Fig.77.

that in the preceding case that no further explanation is necessary ; and indeed Fig. 77 illustrates it perfectly, if we regard *B* as a front view and *A* as a side view.

127. In each case, then, the prism is changed from its original position in Fig. 68, by

rotating it about one of its edges as an axis; in each case the view in the direction of that axis, and also all measurements parallel to it, remain unchanged. Clearly, the same would hold true, whatever the object represented, and the rectangular block was selected only on account of simplicity. But before going on to exercises of greater complexity, it is to be noted that no one of the changes thus far made is sufficient to meet all possible requirements; but by combining them the prism may be drawn in any position which can be assigned.

128. In Fig. 78 the same object is represented in the position described in (**126**). We may now regard this as the original position, and treat it in the same manner as before. In Fig. 79, for example, is shown the result of next turning it about a vertical axis; the top view, C', being therefore a copy of C in Fig. 78, but in a different position. Since the heights also remain unchanged, the new front view A' is constructed by projecting the points *a*, *b*, *c*, *d*, etc., vertically upward from C', with the triangle, and horizontally across from Fig. 78 with the T-square.

In the side view B', which is from the right, as indicated by the arrow *k*, the heights are also the same as in A'; and this view is constructed precisely as was the corresponding view in Fig. 76, by measuring the distance of each point from a vertical reference plane *pp*; which for convenience is passed through the extreme left-hand corner *d*; thus, for instance, in both C' and B' the distances *as*, *ft*, etc., are of the same magnitude.

129. It need hardly be remarked, that instead of copying the view C from Fig. 78, we might have adopted the course illustrated in Fig. 75. Thus, drawing a new base-line $N''N''$, project the various points *a*, *b*, *c*, etc., perpendicularly toward it: the height of each point above the new base-line is the same as that above the original base-line in the front and side views A and B, and is transferred from one of them by direct measurement. In this way the view A' in Fig. 78 is constructed: it corresponds to the view A' in Fig. 79, and would have been identical with it had the direction of the arrow *m* been determined with a view to such coincidence, as was done purposely in Figs. 75 and 76.

No new principle or mode of operation, then, has been introduced, but the object has been turned about two axes in succession. After the revolution about the second axis, it is to be observed that in two of the three views, the foreshortened representations of the faces of the prism are no longer rectangular, some of the right angles appearing obtuse and others acute. But each face is nevertheless represented by a **parallelogram,** in accordance with the deduction previously made, that all lines which in space are actually parallel will appear parallel in any projection; and if also equal in space, their projections will be equal.

This should be always kept in mind, not only because it serves to lessen the labor of construction, but because it is most important as a test of accuracy. And **the triangles should always be used as parallel rulers** in drawing the inclined sides; for since no measurements are to be made from these foreshortened views, it is preferable, if there is any error at all, that it should be in the magnitude, and not in the form.

130. We may now proceed to rotate the prism about the third axis, which is perpendicular to the paper in the side view. The form of this view is not changed by this rotation, and B'' in Fig. 80 is a copy, in a new position, of B' in Fig. 79. In making this copy, it will be found more accurate and more expeditious to construct first the rectangle *syxt* within

Fig.81

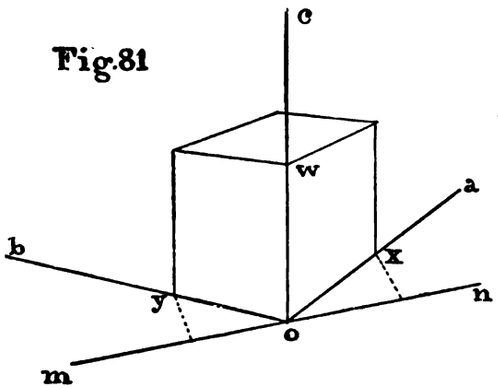
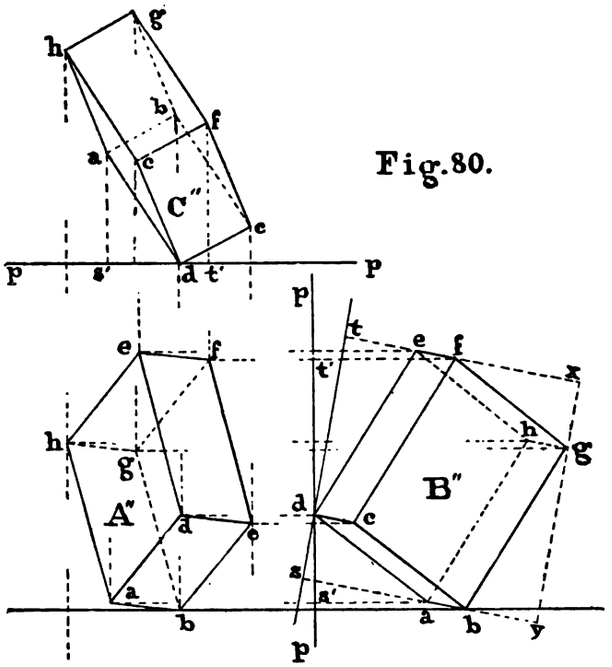
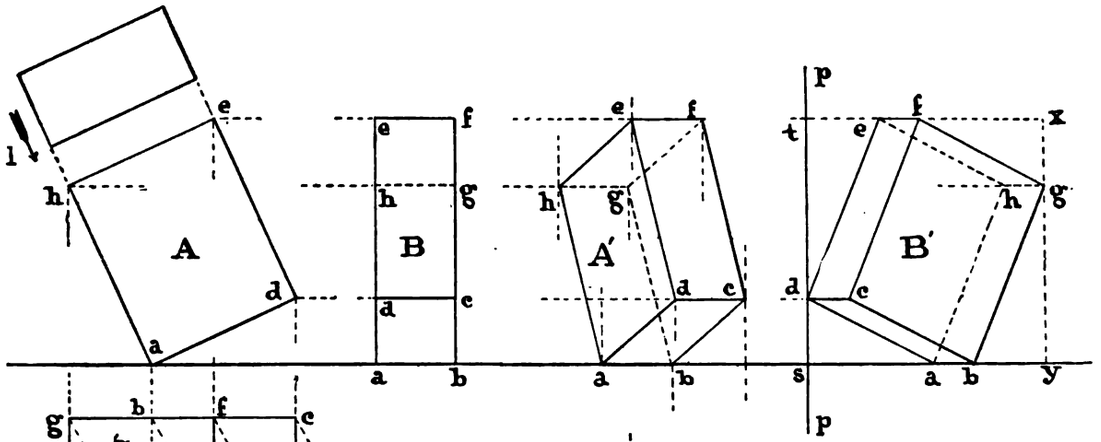


Fig.80.





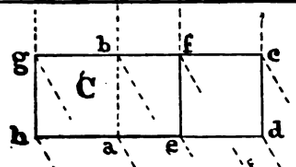
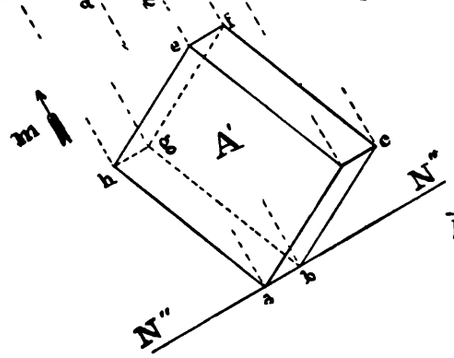
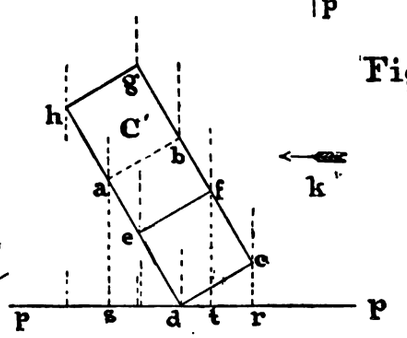


Fig.78.

Fig.79.





which B' is enclosed, and then to set off along its sides the distances *sd*, *sa*, *by*, etc., thus avoiding the direct construction of acute or obtuse angles.

The front view A'' is next laid out by projecting each point vertically upward from the view A' of Fig. 79, and horizontally across from the side view B''. In the top view C'' each point is of course vertically over its representation in A'', and its distance from any convenient reference plane *pp* is the same as in the side view: thus *as'*, *ft'*, etc., are equal in these views,—precisely as in Fig. 79.

As in the cases previously considered, the copying of the side view might have been avoided, and B' made to serve as a member of the group in the final position by drawing a new base-line, and transferring from A' the measurements of breadth for the new front view; but in this case with less advantage, if indeed with any, in respect to the saving of labor; for which reason the process has not been illustrated.

131. Of course, by rotating the prism about the axes in different order, or in different directions and through different angles, it may be placed in other positions than those shown in these diagrams: the student should now be able to construct these for himself, and will find it a profitable exercise to do so.

Since there are at present but three dimensions in space (and there is no immediate prospect of an increase in the number), the prism shown in Fig. 81 may by successive rotations about the three axes *oa*, *ob*, *oc* be placed in any position whatever.

The operations which have been explained, then, cover the whole ground, so far as this object is concerned: given at the outset its projections in the simplest position, we are now able to represent it correctly in the most complicated position, in which none of its sides appears of its true length, and none of its angles is shown in its actual magnitude.

In dealing with objects of any other form, the same principles hold true, and the same modes of procedure are employed. But there is a means of abbreviating the work when it is required to represent an object in such a position as that shown in Fig. 80; and in explaining this it may be as well to adhere to the simple prism for illustration.

132. The position alluded to was derived from the one shown in Fig. 68, by successive rotations about axes parallel to three adjacent edges of the prism. And the proposed abbreviation depends upon the fact that the successive rotations about any two of these are equivalent to a single rotation about another axis lying in the plane of those two, and passing through their intersection. This will be easily seen by the aid of Fig. 81, in which *oa*, *ob* lie in the horizontal plane of the base.

A rotation about *oa* will raise the point *y* above that plane; a subsequent rotation about *ob* will produce the same effect upon the point *x*, while the point *o* will remain fixed. It is clear that a single rotation about any horizontal line *mn* passing through *o* will raise both *x* and *y* above the plane, while *o* as before will remain stationary. The more nearly *mn* coincides with *ob*, the higher will *x* be raised by a rotation through a given angle, and the more nearly it coincides with *oa*, the higher will *y* be raised. By properly selecting the direction of *mn*, therefore, it follows that both *x* and *y* may be lifted to any given distances above the horizontal plane; this will of course determine the inclination to that plane of the new position of *ow*, which line will remain in a vertical plane perpendicular to *mn*. The

direction of *mn* and of the rotation about it being arbitrary, any possible position can be given to the prism by an additional rotation about the vertical axis *oc*.

133. It will often happen in practice that the inclination of the base will be given by requiring that the points *x* and *y* shall be higher than *o* by certain given distances; and the first thing is to determine the direction of *mn* which will effect this, which may be done as in Fig. 82. It is clear that the distances through which those points will rise are directly proportional to their distances, *xd* and *yg*, from the axis *mn*. Let these be, for example, in the ratio of three to five: divide *oy* into five equal parts, and set off *ol* equal to three of those parts; draw *xl*, then *mon* parallel to *xl* is the axis required. For, drawing *xd* and *yg* perpendicular to *mn*, and producing *xl* to *k*, we have

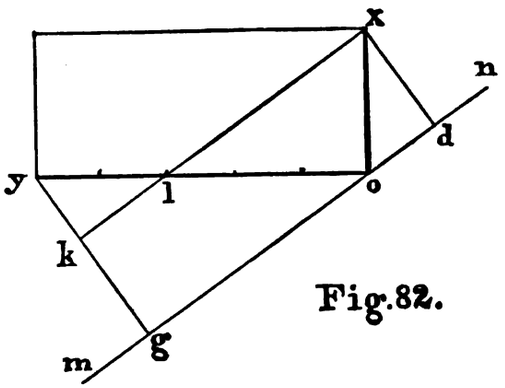


Fig. 82.

$$yg : kg \quad \text{or} \quad xd :: yo : lo.$$

134. Now let it be required to draw the projections of the prism shown in Fig. 83, after it has been turned first about *mn* (which will cause the vertical edge represented by *b* in the top view *C* to appear in the direction *bw* perpendicular to *mn*), and subsequently around a vertical line at *b*, through the angle *wbz*.

The first step is to construct, as in Fig. 75, the view *A'*, looking in the direction *mn*. Then, supposing that the height to which the corner *e*, for instance, is to be raised had been assigned: describe about *e* in this view *A'* an arc with radius equal to that height, and draw the base-line *N'N'* through *a*, tangent to that arc.

Next construct a top view *C''*, looking down perpendicularly to the new horizontal plane thus indicated. In this view the edges *ef*, *gh*, etc., will appear parallel to *N'N'*, and their distances from any convenient vertical reference plane *pp* will be the same as in the original top view *C*. This new view *C''* evidently represents the object with the required inclination to the horizontal plane: now make the angle *z''bv''* equal to the angle *zbv*, shown in connection with the view *C*; then *v''b* will be the direction in which we must look to make the front view in accordance with the assigned conditions.

135. Draw then a final base-line *N''N''* perpendicular to *v''b*; project each point in *C''* perpendicularly toward this, the horizontal plane, and make the height of each point above *N''N''* equal to its perpendicular distance in *A'* above *N'N'*: this new front view *A''* is the one required. From *A''* and *C''*, a side view *B''* is now readily made by the aid of a vertical reference plane *p'p'*, the distance of each point from this plane being the same in the side view as in the top view *C''*.

Now, holding the paper so that *N''N''* is horizontal, the three projections are seen to represent correctly the prism in the position called for; and as there is but one intermediate view to make in passing from the simplest to the most complicated position, **the labor of construction is reduced to a minimum.**

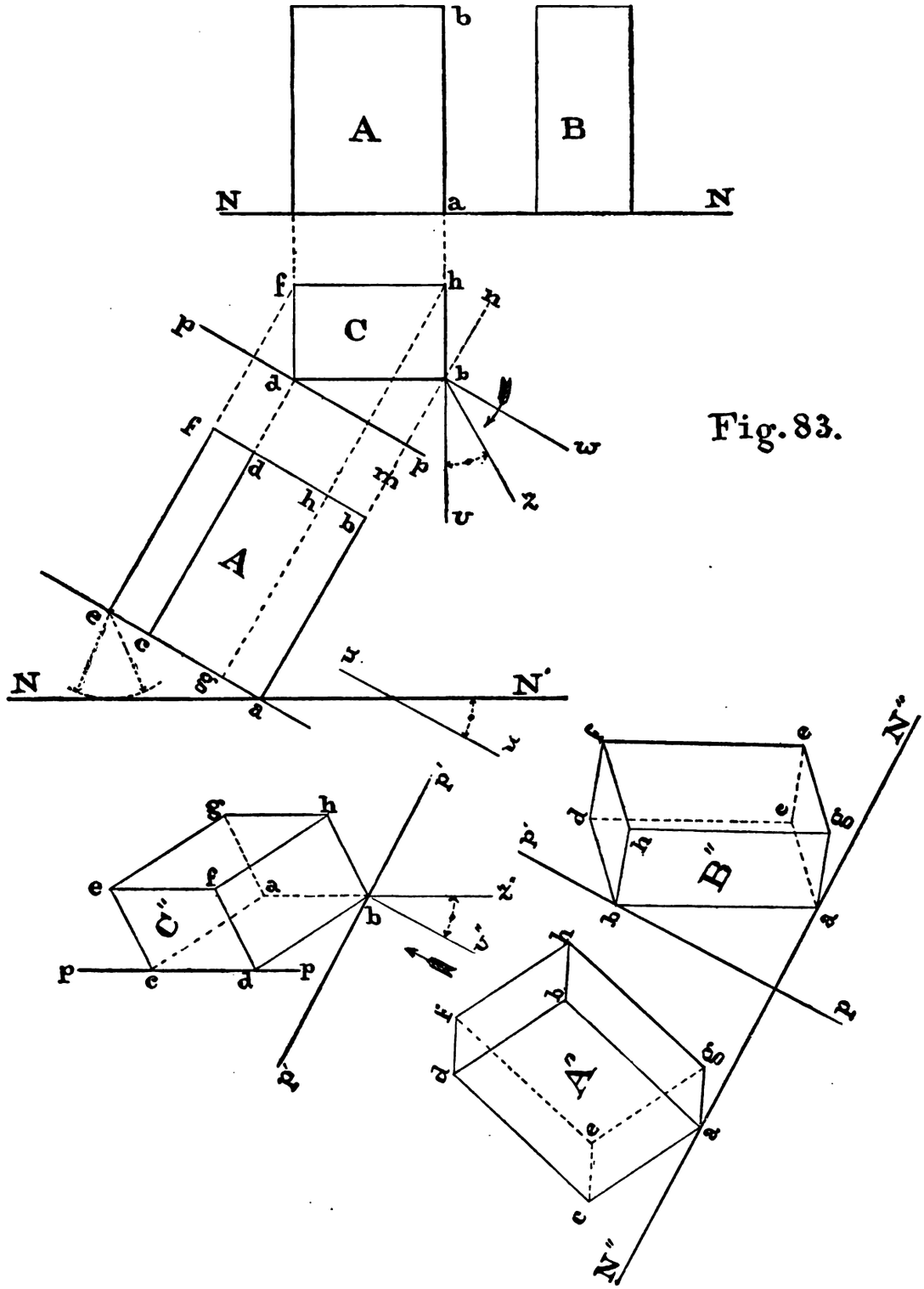

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Fig. 83.

136. It will probably be most often the case that such views are required to be so placed upon the paper that the base-line shall be horizontal: usually, also, there would be no reason for keeping a record of the process of construction, and therefore no occasion for inking in the intermediate view A'. Nor is there any necessity for even pencilling it upon the paper; which may be avoided by constructing it upon a small piece of tracing-paper, on which should also be traced the original top view C, with the line pp. Next drawing a line uu, making with $N'N'$ an angle equal to vbz, the tracing-paper may be turned around and so adjusted as to make uu vertical; after which C'' is drawn at once upon the sheet, below the edge of the tracing-paper, which is removed after the other views have been constructed.

137. It should now be clear that this ultimate position of the object might have been defined by giving the angle which a line, originally vertical, shall make with the horizontal plane, and also the position of the vertical plane in which that line shall lie; for in Fig. 83 the former is determined by the first rotation about mn, and the latter by the second rotation about the vertical axis ab in the front view A.

Thus in Fig. 84 the vertical axis oa appears in the top view C as the point o: let it be required to draw the pyramid when this axis lies in the plane ow, and makes a given angle with the horizontal plane.

First construct the view A', looking perpendicularly toward the plane ow; in this view the base of the pyramid will appear as the straight line bd perpendicular to oa, and $N'N'$, making with oa the given angle ocb, will represent the horizontal plane. From A' and C the new top view C'' is constructed as in Fig. 83; make the angle $w''o''v''$ equal to the angle wov in the original top view C, then $N''N''$ perpendicular to $o''v''$ is the final base-line, from which are set up first the front view A'' by means of C'' and A', as in Fig. 83; then the view D'' from the left by means of A'' and C'', exactly as in the preceding cases.

139. Fig. 85 is a simple exercise, in which A, B, C are the front, end, and top views of a regular hexagonal pyramid, one of whose faces lies in the horizontal plane; D is a view looking perpendicularly at the base, which is thus shown in its true form and size,—an expedient often of great use; and C' is a perpendicular view of the upper face cod of the pyramid, thus showing the true lengths of the slant edges.

In this figure the circle circumscribing the base of the pyramid is drawn in the direct end view D; and this circle must, evidently, be represented in the foreshortened top view C by the curve which passes through the points a, b, c, etc. The base of the pyramid might have had twenty sides as well as only six, without introducing any new principle in projecting it; and the more numerous the points in the circumference of the circle, the more accurately will the foreshortened view of it be determined. But one or two further considerations in regard to drawing such projections of the circle are worthy of special note, since they are very frequently required in working plans of machinery.

140. In Fig. 86 the view A shows the edge of a circular disk, situated as was the base of the pyramid in Fig. 85; and ab in this view also represents the side of the circumscribing square, which is drawn in the view D. In the top view C this square will be foreshortened into the rectangle shown, and the circle will appear as an ellipse, of which xx and yy are the axes. Now constructing the view A'', looking horizontally at C in the direction of the arrow v, the circumscribing square will appear as a parallelogram $abcd$, to the sides of which xx and

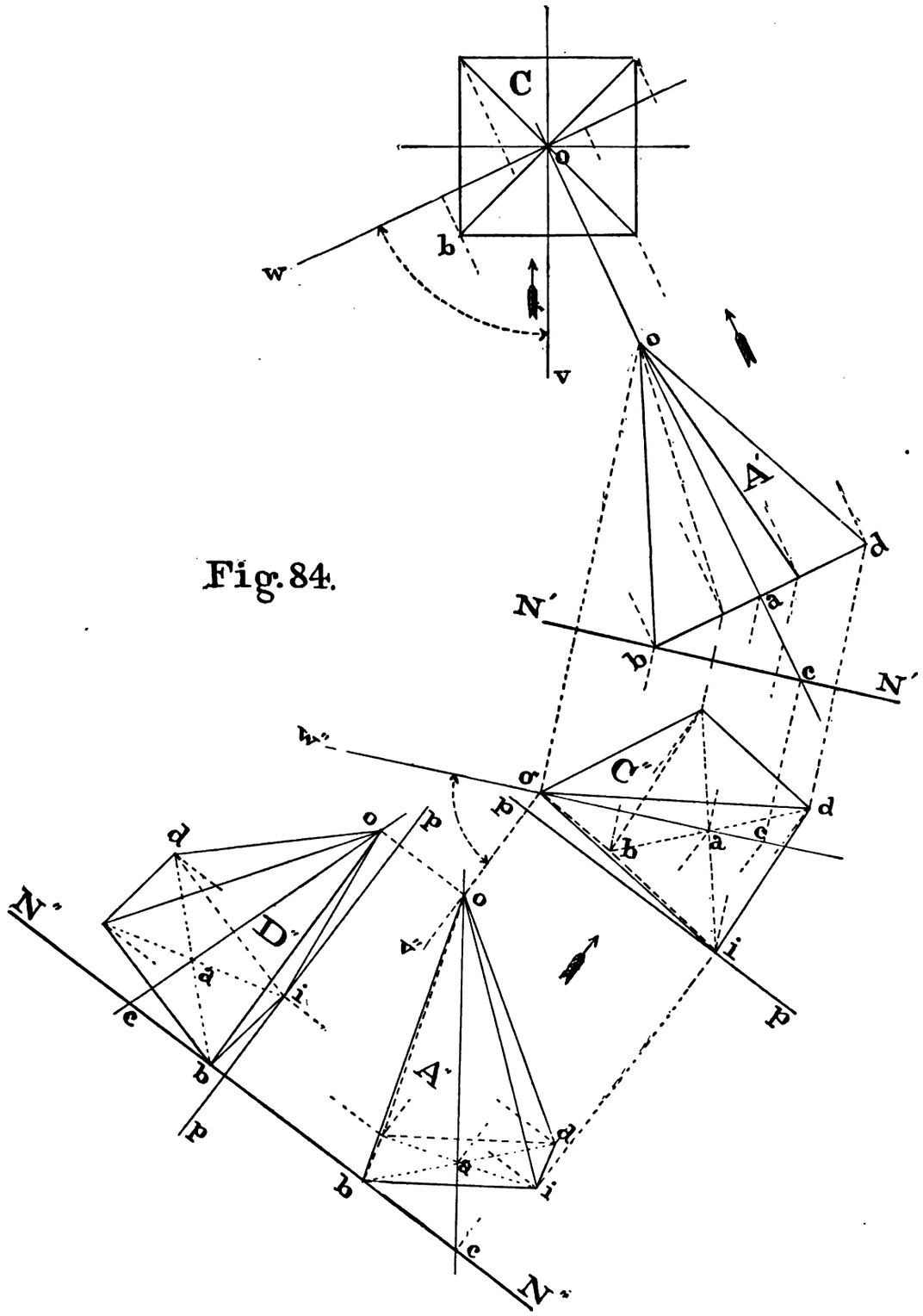

Fig. 84.

yy are parallel: these lines are conjugate diameters, but not the axes, of the inscribed ellipse.

In order to find the axes, we may proceed as follows: Draw a visual ray, that is, a parallel to the arrow *v*, through the centre *o* in the view *C*. This ray being horizontal, a plane perpendicular to it will be vertical, and will cut the plane of the circle in the line *hg*, which will be a diameter, because it passes through *o*, and will in the view *A''* appear of its true length.

Producing *hg* in the view *C* to cut *ad* and *bc* in *m* and *n*, project these points perpendicularly to *ad* and *bc* in the view *A''*, draw *mon* in that view, and set off *oh* and *og* equal to

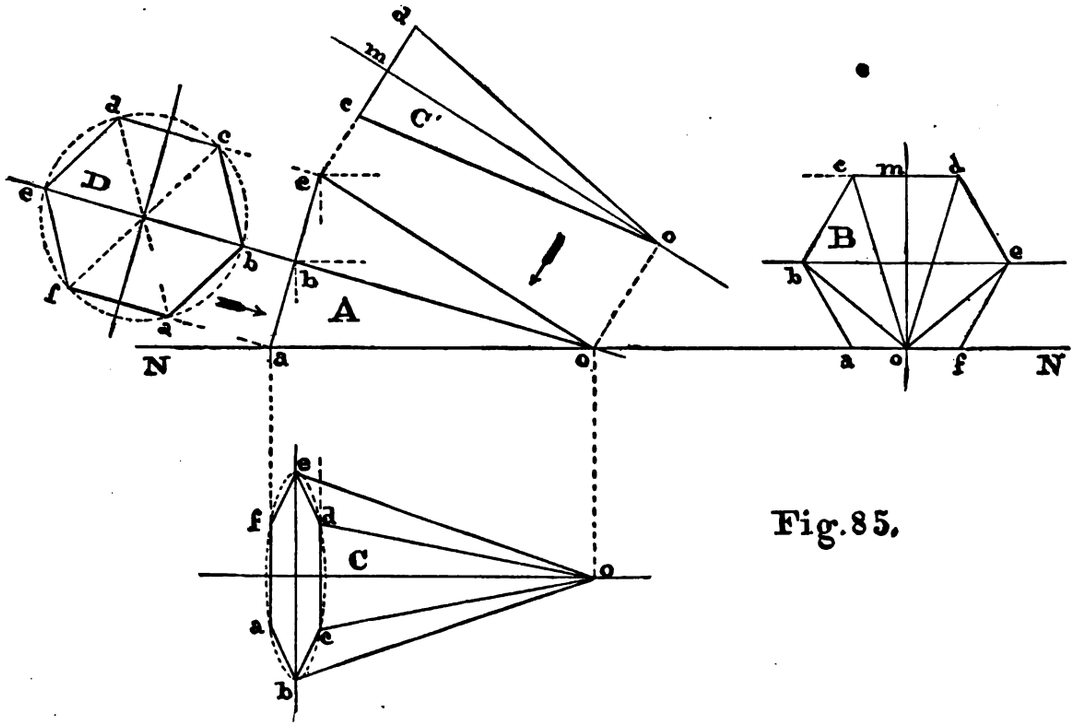

Fig. 85.

the true radius of the circle, given in the view *D*: then *hg* is the major axis, since it appears of its true length, while every other diameter is foreshortened.

141. Since the minor axis is perpendicular to the major, draw in the view *A''* a perpendicular to *mn*, cutting *ab* and *cd* in *k* and *i*; project these points back to the view *C*, in which draw *ik* cutting the ellipse in *p* and *q*, which latter points being projected again to *ik* in *A''*, will determine the length of the minor axis required.

This, however, depends upon the perfection of the ellipse in the view *C*; and if the greatest accuracy is desired, the following method is preferable: Observing that lines parallel to *xx* are not foreshortened at all in the view *C*, we may transfer the measurements *ym*, *yn* directly to the view *D*, and draw *mn* in that view, also *ik* perpendicular to it, thus locating *p* and *q* in the original position of the circle. These points are then projected to the edge view *A*, thus determining their distances above the horizontal plane *NN*. Finally, in the view *A''* draw parallels to *N'N''*, at the distances above it just ascertained in *A*; which will cut *ik* at the required extremities of the minor axis.

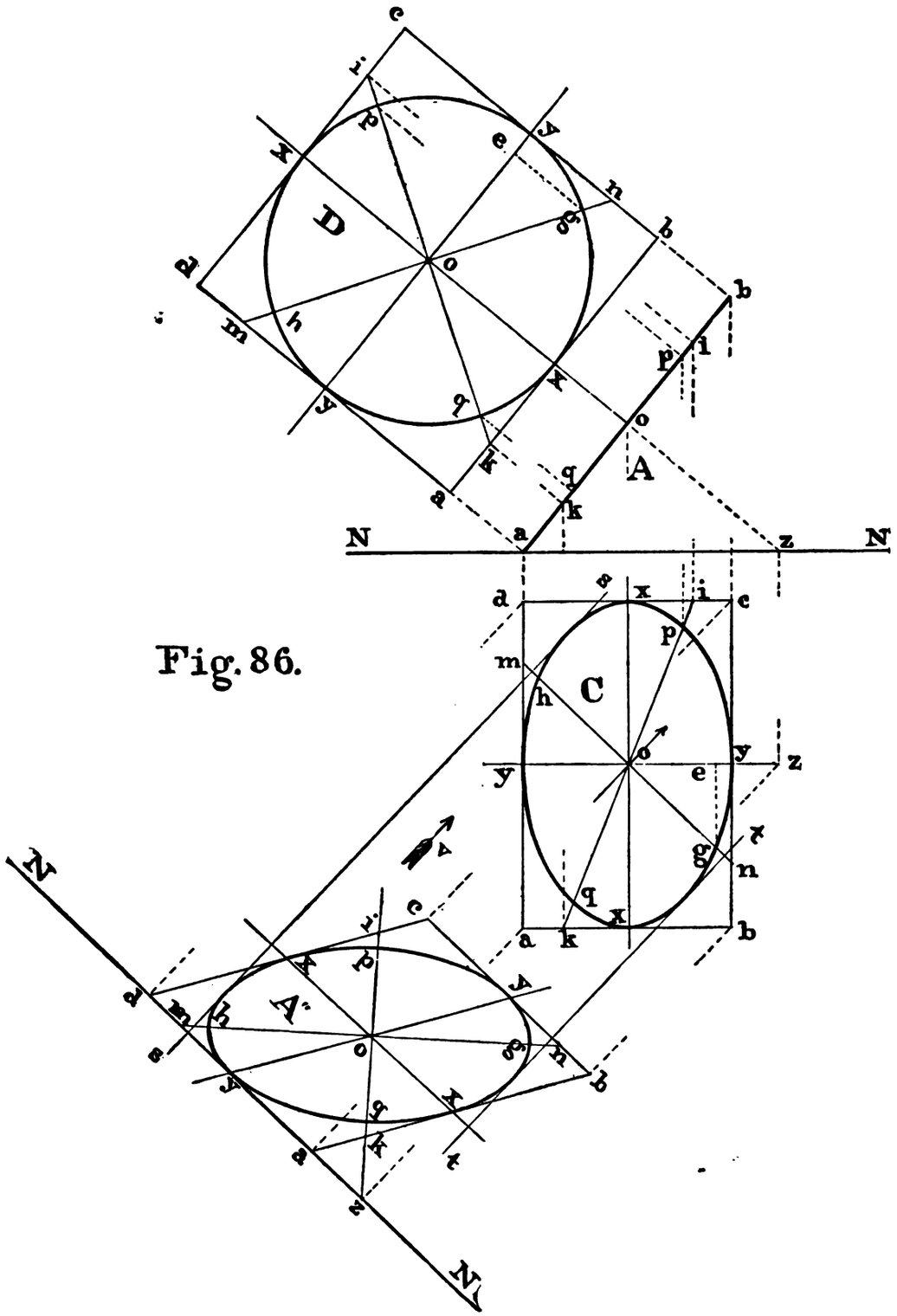
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Fig. 86.

142. These operations are, evidently, outside of the range of projection pure and simple, for they depend upon the mathematical considerations that any projection of a circle is an ellipse, and that any two diameters of the circle which are at right angles to each other will in the projection appear as conjugate diameters of the ellipse. Had the curves been determined simply by projecting a number of points, of course the same result should follow; but the shortest way is always the easiest, and it is perfectly proper to save time by availing ourselves of those known properties for finding the axes, and then to construct the ellipse by any method that is most convenient. And sometimes it is quite important to draw the curves with precision,—as for example in making inclined projections of toothed wheels.

In many cases, however, no such minute accuracy is necessary,—as for instance in representing an inclined cylinder; and in Fig. 87 is shown a shorter process well adapted to such purposes.

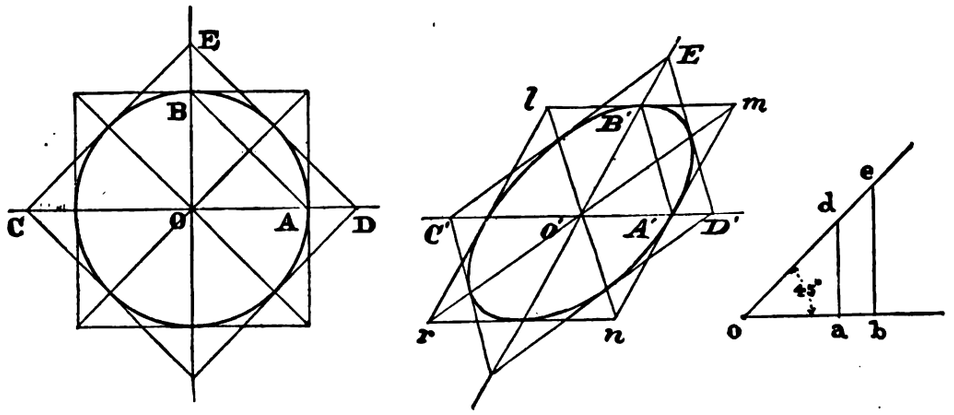

FIG. 87.

143. The circle is shown as circumscribed by two squares, the diagonals of each being parallel to the sides of the other: it is clear then that OA and OD, which in the projection appear as $O'A'$ and $O'D'$, will be foreshortened in the same proportion, and so will OB and OE. This fact renders it unnecessary to draw the second square in the original or direct view of the circle. For, having found the projections of one, *lmnr*, and of its centre-lines, as in Fig. 86, the lengths of the diagonals of the other may be ascertained by a very simple process shown in the diagram at the right: draw a horizontal line, and another making an angle of 45° with it; from the vertex set off oa, ob, respectively equal to $O'A'$ and $O'B'$; at a and b erect vertical lines cutting the inclined one in d and e. Set off $O'D' = od$, and $O'E' = oe$, and draw the sides of the second parallelogram parallel to the diagonals *mr*, *ln*, as shown. We have thus eight points in the required ellipse, and what is of still more service, the tangents at those points.

It may perhaps be added, that short portions only of the lines made use of in this illustration need be actually drawn in practice; with due attention to this precaution, this method is both neat and expeditious.

144. Application of the foregoing may be made in constructing the projections of the cylinder given in Fig. 88, of which no detailed explanation is needed.

But in whatever position the cylinder is placed, it is possible to conceive two planes

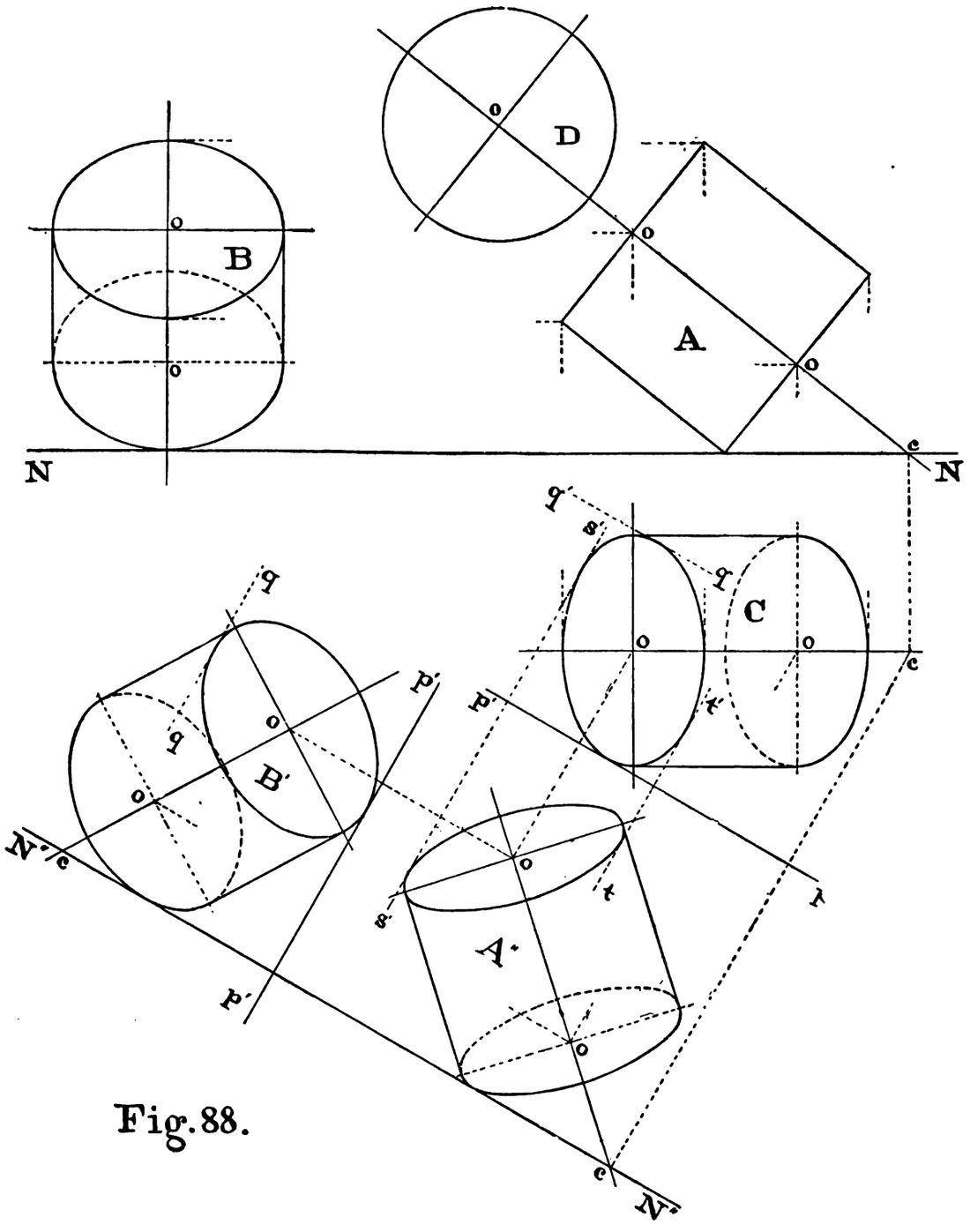

Fig. 88.

tangent to it on opposite sides, and parallel to the direction in which we are looking: these planes will touch it along two lines parallel to the axis, and the least distance between them will be equal to the diameter of the cylinder.

From this it follows, that in any projection the apparent diameter will be equal to the real diameter; and also that if in any view, as for instance A'' in Fig. 88, we first determine oo, the projection of the axis, then a line perpendicular to that projection at either extremity, and equal to the actual diameter of the cylinder, will be the major axis of the ellipse representing the corresponding base.

And it is to be noted also that in Figs. 86 and 88 the ellipses in views C and A'' have on opposite sides the common tangents ss, tt, perpendicular to $N''N''$; which fact, if the first ellipse is correctly laid out, is of service in constructing the second, even if the point of contact be not determined—which indeed is practically of no consequence whatever.

CHAPTER V.

OF THE HELIX, AND ITS APPLICATION IN THE DRAWING OF SCREWS.

145. The helix is a curve traced upon the surface of a cylinder by a point which moves at a uniform rate around the circumference, and at the same time travels uniformly in a direction parallel to the axis. But though both motions are uniform, their rates are independent of each other; while going once around the cylinder the point may advance in the direction of the axis to any distance, great or small, at pleasure, and this distance between the successive coils is called the **pitch.** The directions of the two motions are also independent of each other, and thus the helix may be either **right-handed** or **left-handed:** to use a homely illustration, there are two directions in which a string may be wound around a stick.

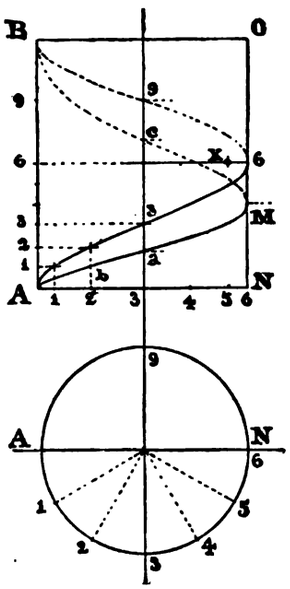

FIG. 89.

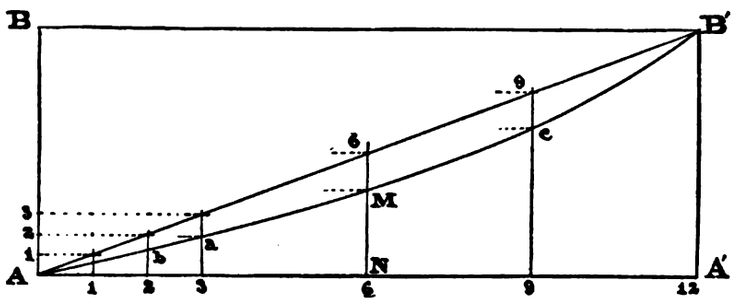

FIG. 90.

In Fig. 89 are given a side view and a top view of a vertical cylinder. In the top view, beginning at A, divide the circumference into equal parts by the points 1, 2, 3, etc., and project these points up to the lower base of the side view; where of course the divisions, being unequally foreshortened, will not appear equal.

In the side view set off along AB equal spaces, numbering them also 1, 2, 3, etc., from A. Through each of these points on AB draw a horizontal line, and through the divisions on AN draw vertical lines: the intersections of those correspondingly numbered will be points upon the helix $A369B$. The portion $A36$, lying on the front side of the

cylinder, is visible, and shown in a full line; the portion 69B is hidden, lying on the back of the cylinder, and therefore shown in a dotted line.

146. It is easy to see that the visible portion $A36$ is divided at the point 3 into two equal and similar parts, $A3$ being concave toward AN, while 36 is convex toward that line. The curvature is most rapid at the points A and 6, diminishing toward the point 3, which is the point of **contrary flexure.** The radius of curvature being infinite at this point, the curvature of the helix for some distance on either side of it will be almost imperceptible, and this part of the line is practically best drawn with a straight-edge. And the same is true with regard to the concealed portion 69B.

It is equally apparent that the visible part is exactly similar to the invisible part; the horizontal line 66 is a line of symmetry, and the curve 69B above it is a reproduction of 63A below it, in a reversed position.

147. Moreover, **the projection of the helix is tangent to the visible contour of the cylinder:** thus, AB is tangent to the curve at A and B, and NO is tangent to it at the point 6, which is the vertex of the portion 369, symmetrical about the horizontal 66.

For this reason it is advisable always to use the bow-pen for drawing a small portion of the curve on each side of the vertex, finding by trial and error the proper radius and the centre x upon the line of symmetry 66; the same radius being of course used wherever applicable at other points, as at A and B in this figure.

Since the curvature changes most rapidly near these vertices, care should be taken to find points near each other in these parts, in order to locate the centre x with a reasonable degree of precision; which is absolutely essential to a successful representation of the helix, an error at the vertex being more conspicuous than in any other portion of the curve.

148. Suppose the cylinder to be made of a thin sheet of metal, and cut lengthwise along the line AB: it may then be unrolled into a flat sheet, shown in Fig. 90, of which the breadth AB is equal to the length of the cylinder, and the length AA' is equal to the circumference. This is called the **development** of the cylinder; and since the unrolling involves no distortion, extension, or compression in any part of the metal sheet, the equidistant points 1, 2, 3, etc., on the circumference in Fig. 89 will appear as equidistant points on AA' in Fig. 90; and the same is true of the divisions on AB. Therefore, drawing horizontals through the latter and verticals through the former, the intersections of the correspondingly numbered ones must be points on the development of the helix. From the constant ratio between the bases and the altitudes of the triangles thus formed, it follows that this development must be a right line: which in this case is a diagonal AB' of the rectangle, because the pitch of the helix is equal to the length of the cylinder.

149. It is quite plain that this operation might be reversed; were a sheet of thin paper cut into the form of the triangle $AA'B'$, and rolled around a wooden cylinder of the given dimensions, its hypothenuse would coincide with the original helix, the vertical lines upon it also coinciding with those first drawn upon the cylinder.

Now suppose the upper edge of the paper cut in the form of the curve AMB': it is clear that this edge when wrapped round the cylinder would *not* form a true helix. But we can easily determine the projection of the curve which it would form, since the vertical lines on the paper would go back to their original places on the cylinder, and their lengths are given

in the development. In constructing the drawing, then, we have only to project the points *a*, *b*, *M*, *c*, etc., in which these verticals cut the curve in Fig. 90, horizontally back to the correspondingly numbered verticals in Fig. 89.

It follows from the above that the shortest line which can be drawn on the surface of a cylinder, between two given points which lie neither upon the same circumference nor upon the same right line, is a helical arc. For on the development these points will appear at their true distance from each other; and the right line joining them, being by the conditions neither horizontal nor vertical, will become a helix when the developed sheet is re-formed into a cylinder.

150. The helix is sometimes called a *linear screw*, and may be traced by the point of a cutting tool moving endwise at a uniform rate along a cylinder revolving in a lathe, and just in contact with its surface. If the tool be fed farther in toward the axis, a helical groove will be cut, of a form depending on the shape of the cutting part of the tool; and if the pitch be great enough, a helical projecting ridge will be left, and this is called a screw-thread. We say if the pitch be great enough; for if the longitudinal travel be very slow, it is easy to see that this thread will be entirely cut away, and the operation will result in merely turning down the original cylinder to a smaller diameter. By varying the shape of the tool, then, screws of various forms may be produced, of which the most common are the square-threaded and the V-threaded.

THE SQUARE-THREADED SCREW.

151. A clear idea of the square-threaded screw may be formed by imagining a square rod of lead to be coiled around a cylindrical core, like a string around a stick, leaving a space, as wide as the leaden bar itself, between the adjacent coils. Thus in Fig. 91 *aeif* is the section of this bar; after making a half turn it appears in the position *cglm*, and at the end of a whole turn in the position *dkon*; since the groove is to be as wide as the thread, $fd = af$, and $ik = ei$. Also, *af*, *cm*, *dn*, *jz* will lie upon the surface of a larger cylinder, in which the helical groove might be cut as before explained.

The line *ae* is perpendicular to the axis, which it would cut at *v*, and if still farther prolonged it would cut the opposite sides of the two cylinders at *u* and *w*. Now *ad*, or its equal *fn* (being the breadth of the thread plus that of the groove), is the pitch of the screw; in going from *a* to *d*, the point *a* describes a helix *abcd*, lying on the surface of the outer cylinder, and in going from *e* to *k*, the point *e* describes a helix *ebgk*, lying on the surface of the smaller cylinder: similarly, *f* and *i* describe the helices *fhmn*, *ihlo*, and all the other curves, for successive threads, are simply repetitions of these.

152. In order to make the drawing neatly, as few lines as possible should be pencilled in, and very few are in fact necessary. Having lightly drawn the outlines of the outer and inner cylinders, and the axis, an indefinite vertical line through *a* determines the points *e*, *v*, *u*, *w*; then, observing that $vb = \frac{1}{4}$ pitch, and $wc = \frac{1}{2}$ pitch, the vertices of the helices, as *f*, *d*, *n*, *l*, *m*, *j*, etc., as well as the points *h*, *p*, *q*, etc., on the axis, may at once be set off by means of the scale; and very short vertical lines only need be drawn with the triangles through the vertices, on which are located the centres of the small arcs to be drawn with the bows. Let

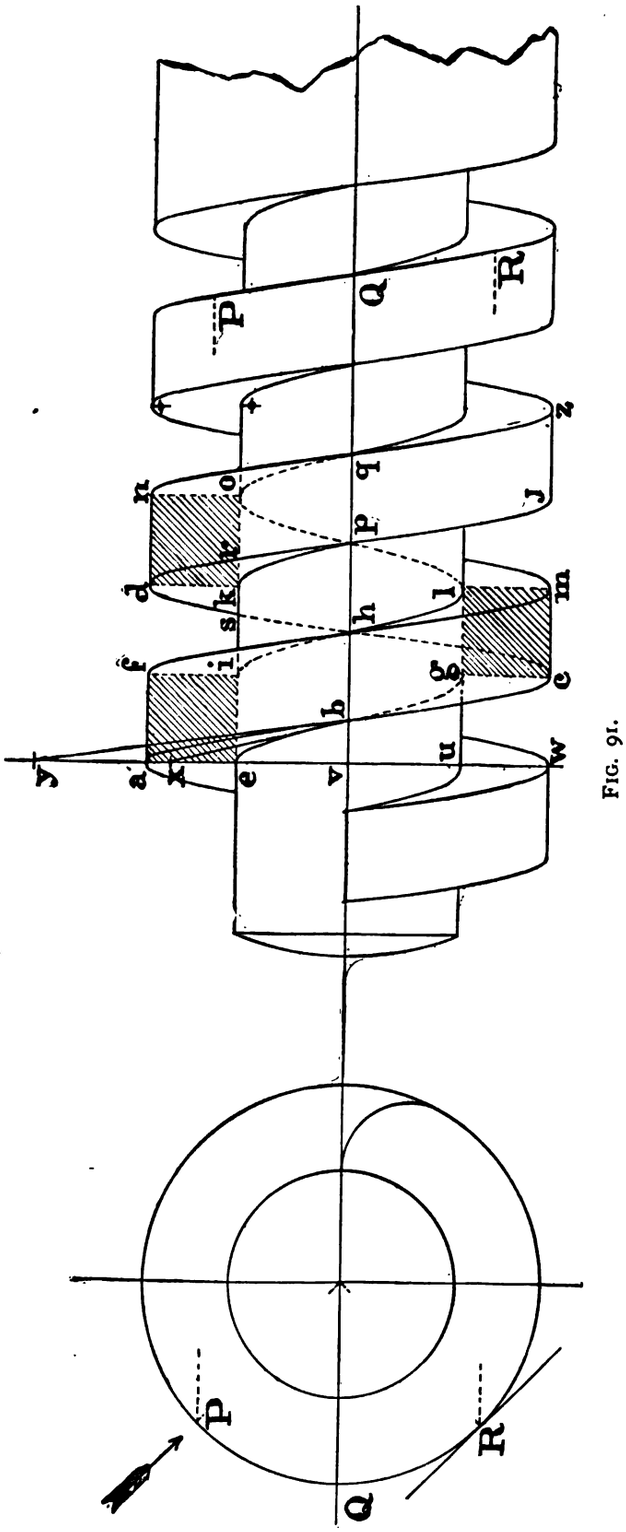

FIG. 91.

now the visible portions of the helices for one half of a thread, as *sdrp*, *nq*, *kp*, be carefully constructed and traced on a piece of tracing-paper, on which are also to be drawn the axis and the vertical lines *dk*, *no*. Turn the tracing-paper over and trace the lines carefully with a pencil of medium hardness, on the opposite side, then turn it over again to its original position; by sliding it along and adjusting it to the positions of the successive threads, the lines on its back may be transferred to the paper below by going over them carefully, with a firm pressure, with a pencil. Having thus made impressions or transfers for the upper halves of the threads, turn the tracing-paper end for end, and repeat the operation for the lower halves.

153. In the construction of the curves particular attention should be paid to the fact that the visible portion *ds* on the remote side is in the projection precisely similar to the corresponding portion *dr* on the nearer side, *dk* being the line of symmetry, so that $ks = kr$; and also to the fact that *kp* is not tangent to *drpj*, but intersects it at *p*, at an angle which may be determined as follows:

The helical arc *ab* embraces one fourth the circumference of the cylinder, and the corresponding linear advance is *vb*, one fourth the pitch. On *va* produced set off *vy*, equal to the quarter circumference, then *by* is tangent to the helix at *b*; and the angle *vyb* is the measure of the **obliquity** of the curve. With the same pitch, the obliquity will be the

greater the smaller the cylinder: set off then *vx* equal to the quarter circumference of the core, then *bx* is tangent to the inner helix, and *vxb* is its obliquity.

If, in inking in, small portions of the helices near the axes are drawn with the straight-edge, these tangents should always be constructed and the triangles set so as to make those straight portions parallel to them.

154. When a very long screw has to be drawn, it will facilitate matters and save time to make a template of a thin slip of white holly, cut to the exact form of the helical curve. The centre-line should be drawn upon this, and it is used in connection with the T-square as shown in Fig. 92; it is necessary only to slide it along to bring the point *o* successively to the positions *b*, *h*, *p*, etc., in Fig. 91. In making such a template, no attempt should be made to carry the helical curve farther than the points of contact with the small circular arcs at the vertices, as at *f*, *m*, Fig. 91, for neither pencil nor ruling pen can be successfully used to draw such sharp curves by any template, concave or convex; beyond those points, the outline should be straight, and tangent to the helix. Such small portions of the inner helices are

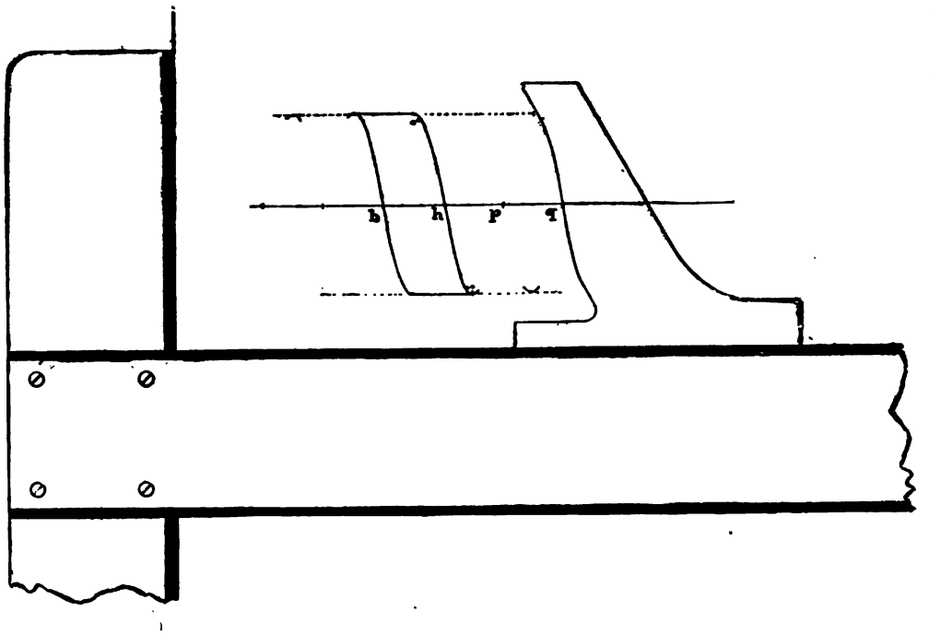

FIG. 92.

seen in the drawing, that it is seldom or never worth while to make a template for drawing them.

Should proper wood for the purpose not be at hand, it is well to know that such curved rulers can be made of heavy card-board or Bristol-board to good advantage: this should receive on each side one or two coats of shellac varnish, and when well dried it will then be found easy to produce a very satisfactory drawing edge by means of fine files and sand-paper.

155. The effectiveness of the drawing will be much enhanced by the proper use of shadow-lines. The arrow shown in the end view at the left of Fig. 91, being drawn toward the centre, is normal to the surface at *P*, at which point the light is most concentrated; the

corresponding point in the side view is therefore the one at which the shadow-line should be heaviest; from P to Q it may be substantially uniform, but from Q to R it should be gradually diminished in thickness, merging at the latter point into the unshaded outline. Undeniably, a shadow is cast by the helix up to the very highest visible point; but the surface above P is receding, and the shadow-line is therefore tapered off rapidly above that point, in accordance with the general principle that the heavier the shadow-line, the more pronounced is the effect of relief.

156. If we suppose an iron screw to be put into a mould as a core, and type-metal to be cast around it, it will be seen that this metal will exactly fill the groove. The surface of the nut thus formed, then, is identical with the surface of the screw: if now, without unscrewing the iron core, we plane off one half of the whole, down to the axis, it is evident that the outline of this longitudinal section of the nut will coincide precisely with that of the section of the screw. Consequently, if the remaining half of the screw be taken out, the interior of the nut will exhibit lines which, from the manner in which it was made, must be identical with those portions of the helices lying on the farther side of the screw, and therefore not visible in Fig. 91. Such a section of the nut is shown in Fig. 93, and requires no farther explanation, except

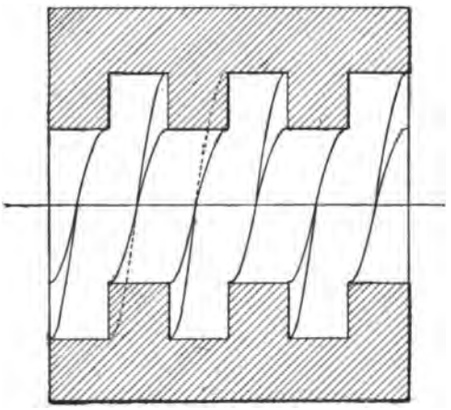

FIG. 93.

to call attention to the circumstance that all shadow-lines except those lying in the plane of the section are omitted, since all the edges which would cast shadows lie upon *receding* surfaces.

157. The screw shown in Fig. 91 is a **single-threaded** one; now if we wind the same bar around the same core, but double the pitch, the groove will be three times as wide as the thread. In the middle of this groove we may wind another bar of the same section, thus forming a **double-threaded** screw. Or, what comes to the same thing, if we cut in the lathe a groove of the same size as that shown in Fig. 91, but of twice the pitch, there will be left a thread three times as wide, in which another similar groove may be cut. A double-threaded screw, with a section of its nut, is shown in Fig. 94.

Clearly, the groove may be made deeper or shallower at pleasure, and wider or narrower than the thread; also, by trebling the pitch we may add another thread of the same size, and

so on indefinitely. But unless the diameter is increased, the obliquity of the helices will become greater with each additional thread, until at last it would be impossible to turn the screw in the nut if the latter were fixed.

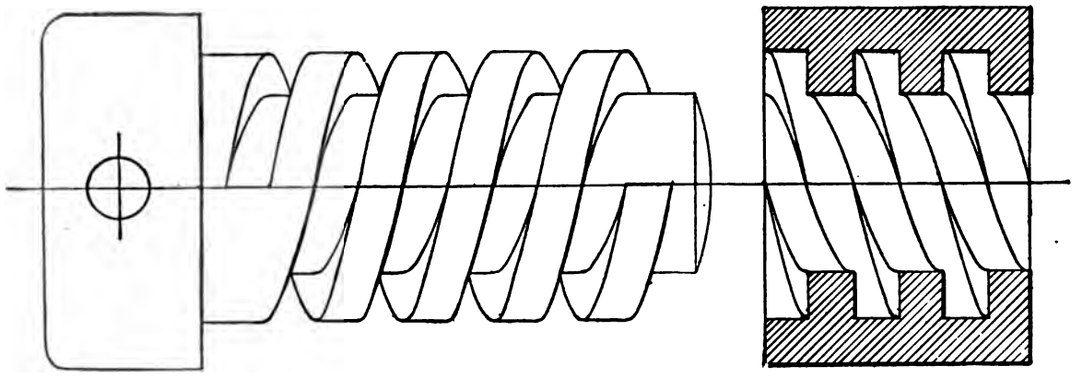

FIG. 94.

Examples of such multiple-threaded "quick" screws are found in the so-called "Archimedean" drills, which are rotated by sliding the nut endlong. None of these variations, however, involve anything in regard to the making of the drawings beyond what has been explained.

158. The operation of winding a rod or bar around a cylindrical core, which we have used as illustrating the formation of a screw-thread, is of course actually performed in the making of helical springs. The "wire" of which these are made is usually either round or square in transverse section, although other forms are occasionally employed.

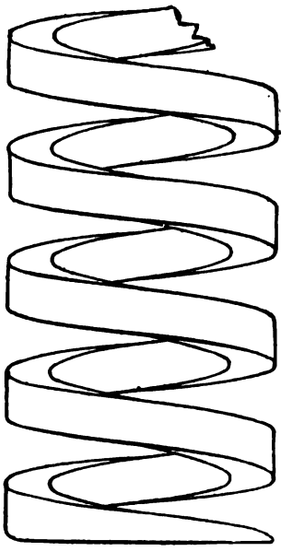

FIG. 95.

The appearance of the spring, after withdrawing the core around which a square bar has been wound, is shown in Fig. 95; it requires no special explanation, the visible lines being portions of the helices into which the edges of the bar have been twisted, and short parts of the rectilinear elements of the outer cylinder.

But if a round bar be thus coiled into a helical spring, its axis will be twisted into a helix lying on the surface of a cylinder, whose diameter is that of the core plus that of the bar. Now suppose a fine wire to be coiled into the form of this helix, and a hole of the same size and curvature as this wire to pass through the centre of a sphere of the same diameter as the bar. Since the curvature of the helix is everywhere the same, the ball could slide along the wire, and in every position would just fit a similarly coiled tube of the same diameter.

Having drawn the central helix, then, describe a number of circles, with centres on this helix, and a radius equal to that of the bar; the envelope, or curve tangent to all these circles

will be the visible contour of the coiled rod, as shown in Fig. 96. A moment's study will show that the line *ab* of this contour cannot extend beyond the point *i*, at which it is tangent to the outline of the sphere whose centre is *c*, the vertex of the central helix *ocp*; and in like manner the line *de* must disappear at *l*, where it is tangent to the outline of the sphere whose centre is *o*; and similarly in regard to the other coils.

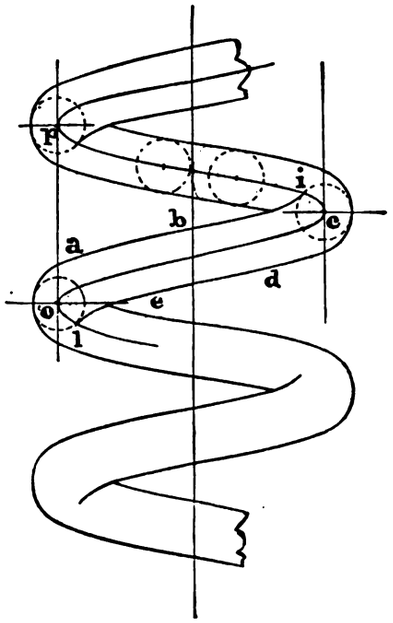

FIG. 96.

The operation just described is the most expeditious as well as the most accurate method of determining the correct visible contour of the helical coil, and is to be employed when the object is of considerable dimensions, as in the case of a very large spring, or the worm of a still.

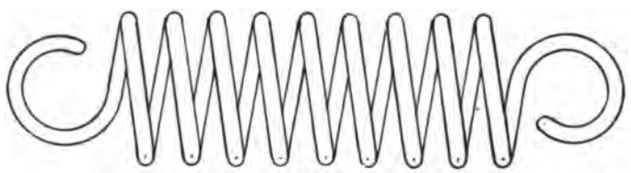

FIG. 97.

But springs are seldom so large as to render this labor necessary: under ordinary circumstances, the mode of representation shown in Fig. 97 answers all purposes, care being taken to locate correctly the centres of the small circles, to which straight parallel tangents are drawn; the curvature of the helix being slight, may be neglected.

THE V-THREADED SCREW.

159. This may be formed by winding a flexible bar of triangular section, base downward, upon a cylindrical core, as shown in Fig. 98. The pitch is here made equal to the base of the triangle, so that the sections of adjacent coils, as *aef*, *fgh*, just touch each other at the root of the groove left between them, where they have the common point *f*: this forms what is called the **full sharp** single-threaded screw, which of course is actually made in practice by cutting the triangular groove with a sharp-pointed tool.

Now in winding the flexible bar it is at once seen that the outer edge *a* is twisted into a helix *alq* lying on the outer cylinder, whose outline is *avg*; and the lower edge *e* into a helix lying on the surface of the core.

In like manner the intermediate points *b*, *c*, *d* of the side *ae* of the section will describe helices lying on intermediate cylinders: these will have different obliquities, because they have the same pitch, *ag* or *ef*. Were these actually engraved upon the surface of the screw, it is evident that they would be visible on the nearest side, up to and beyond the points *b*, *c*, *d*, but would finally disappear. Since they lie *upon* the surface, then, and do not go outside of it, the **visible contour** must be bounded by a line *ik*, **tangent to all the helices**: the line *ae*, on this side of the thread, is still visible; but it is not the outline, and therefore is not shown in the finished drawing.

160. Similarly, the visible contour of the right-hand side of the thread will be a line *lm*, tangent to all the helices described by the points on the line *af*. But since it *is* the visible contour, those helices will disappear from view at the points of contact with *lm*; the outline of the section *af* being thus concealed by an intervening portion of the thread.

Obviously, the same reasoning and the same process would enable us to determine the extreme outline of a thread whose section was of any other form, symmetrical or otherwise.

And it is equally clear that when, as is usually the case, the section *is* symmetrical with regard to a line, as *aw*, perpendicular to the axis, the contour-lines *ik* and *lm* will be similar, and also symmetrical in respect to the same line.

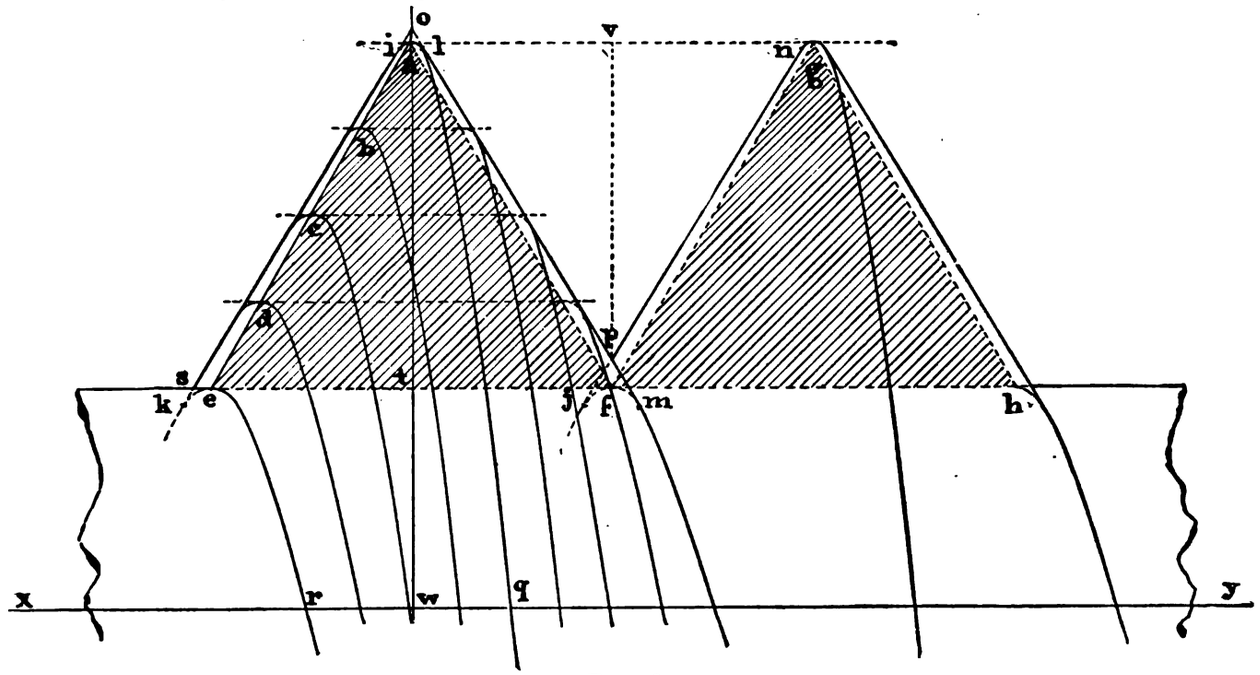

FIG. 98.

In the figure the triangle *aef* is equilateral, because in the U. S. standard screws the sides of the threads and grooves are inclined to each other at an angle of 60°. This being so, it is to be observed that the contour-lines are in reality slightly concave; but with the usual proportions between the size of the thread and the diameter of the core (practically determined by considerations of strength), the curvature is too slight to be appreciable.

161. It suffices, therefore, to draw only the outer and the inner helices, *aq* and *er*, carrying them well beyond the vertices *a* and *e*, and to draw a straight line tangent to these two. This tangent should be prolonged to cut the vertical line through *a* in the point *o*: then *lm* will also pass through *o*, and the angle *wom* will be equal to the angle *wok*; also, be it noted, each of these angles will be greater than *wae*.

The contour-lines will be tangent to the outer helix at two points *i* and *l*, on opposite sides of the vertex and equally distant from it; and this small arc is best drawn with the bow-pen. The thread, then, though actually sharp at the top, does not appear so in a correct side view of the screw, when the axis is parallel to the paper, as it usually is.

In regard to the groove, the case is different: and here it is to be observed that since *nj*,

the left-hand side of the next thread, is parallel to *ik*, it will cut *lm* at some point, *p*, on the vertical line through *f*, but some distance above it.

The groove, therefore, does appear sharp, though not as sharp as it really is; the bottom of it (or the actual root of the thread) is not visible; and the apparent depth, *vp*, is less than the full depth. In Fig. 98 only the upper half of the screw is shown; which however is sufficient, since if simply inverted it represents the lower half just as well.

Accordingly, in Fig. 99, which represents the entire screw, *o'k'* is parallel to *ok*, and *o'm'* parallel to *om*. In order to make the screw enter the nut readily, the thickness of the last thread is reduced by turning it off by a plane perpendicular to the axis; the end of the thread

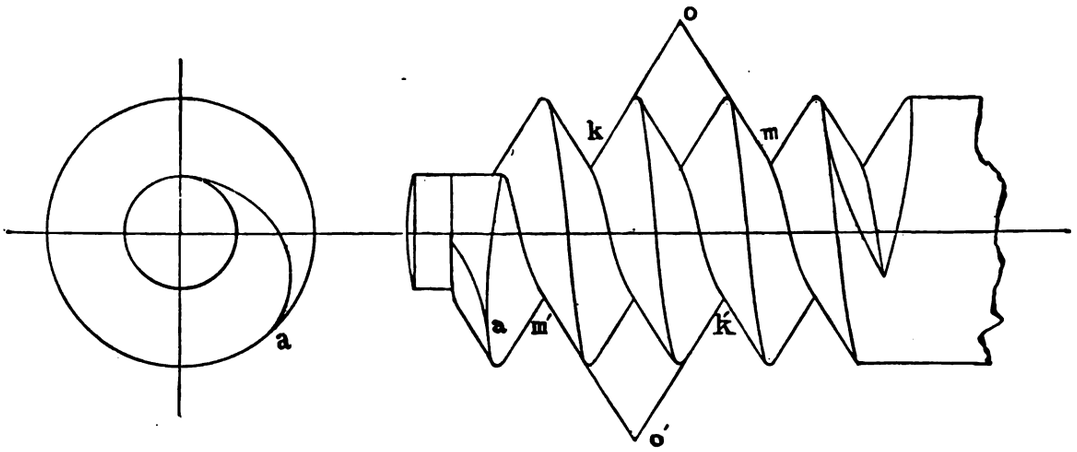

FIG. 99.

is also rounded as shown in the end view, thus producing in the side view two curves tangent to each other and to the outer helix at *a*.

162. A section of the nut is given in Fig. 100. In relation to this, it is a common error to suppose that its contour should correspond with the visible contour of the screw, as *alpng* in Fig. 98. That this is not the case will be clearly seen by imagining the nut, as before suggested, to be made by casting type-metal around the screw, which, expanding as it solidifies, must exactly fill the groove and fit the screw. A section of both screw and nut by a plane through the axis will then show but one contour-line common to the two; and this will be composed of right lines, intersecting each other, in the case here illustrated, at angles of 60°, with no rounding off or curvature of any kind whatever, as shown in the figure.

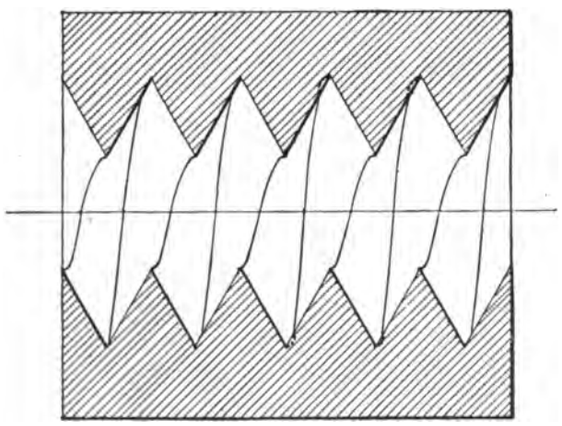

FIG. 100.

On removing the remaining half of the screw the outer and inner helices on the interior of the nut will be exposed; small portions of the

former, near the vertices, will be hidden on account of the twist of the surface, but the latter will be visible from vertex to vertex.

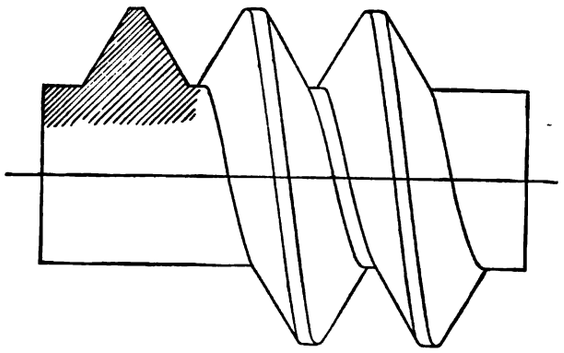

FIG. 101.

163. The threads of bolts are seldom made "full sharp," but are usually made flat on the top, the groove also being flat on the bottom, as shown in Fig. 101. In the complete drawing, therefore, the bottom of the groove is usually seen, as in the figure: the construction does not involve any considerations beyond those already presented, but it may be as well to call attention to the fact that the contour-line *ik* in Fig. 98 intersects the upper outline of the core at a point *s*, at a small but yet a perceptible distance **to the left of the vertex,** *e*, of the inner helix.

It need hardly be added, that V-threaded as well as square-threaded screws may be made, and sometimes are required to be, left-handed as well as right-handed, and with two, three, or any other number of threads. Screws are also sometimes made with a different slope on one side of the thread from that on the other, or even with threads whose section is bounded by curved lines. It is not, however, necessary to illustrate these variations, as due attention to the foregoing will enable the student to draw them correctly.

164. In the preceding illustrations of the application of the helix in the drawing of screws and nuts no attention has been paid to the customary proportions of diameter to pitch and depth of thread. The usual conditions have been purposely exaggerated in order to emphasize the peculiarities of the curve. And this has been done with a set purpose: in the ordinary course of mechanical drawing for constructive purposes, bolts and nuts are very seldom met with which need to be drawn with such minute precision as has been heretofore insisted on; and in Part II a chapter is devoted to the illustration of what may be called conventional methods of representing them when used, as they mostly are, merely as a means of fastening various parts together.

But the helix is encountered by the mechanical engineer on much larger scales in the construction of screw-propellers; and in laying out the drawings for these the utmost exactness in regard to this fundamental curve is necessary.

No illustration of this application is here introduced, because the drawing of even the simplest form of the propeller in use involves problems relating to the intersection of surfaces which could not be reasonably discussed at this stage. In the mean time, a thorough understanding of the processes relating to the correct delineation of the helix can be acquired, independently of the application of the curve to that or any other purpose.

CHAPTER VI.

INTERSECTIONS AND DEVELOPMENTS OF SURFACES.

165. In Fig. 102 a vertical hexagonal prism is represented as cut by a plane *pp*. Since this plane is perpendicular to the paper, the points in which it cuts the edges 1, 2, etc., are

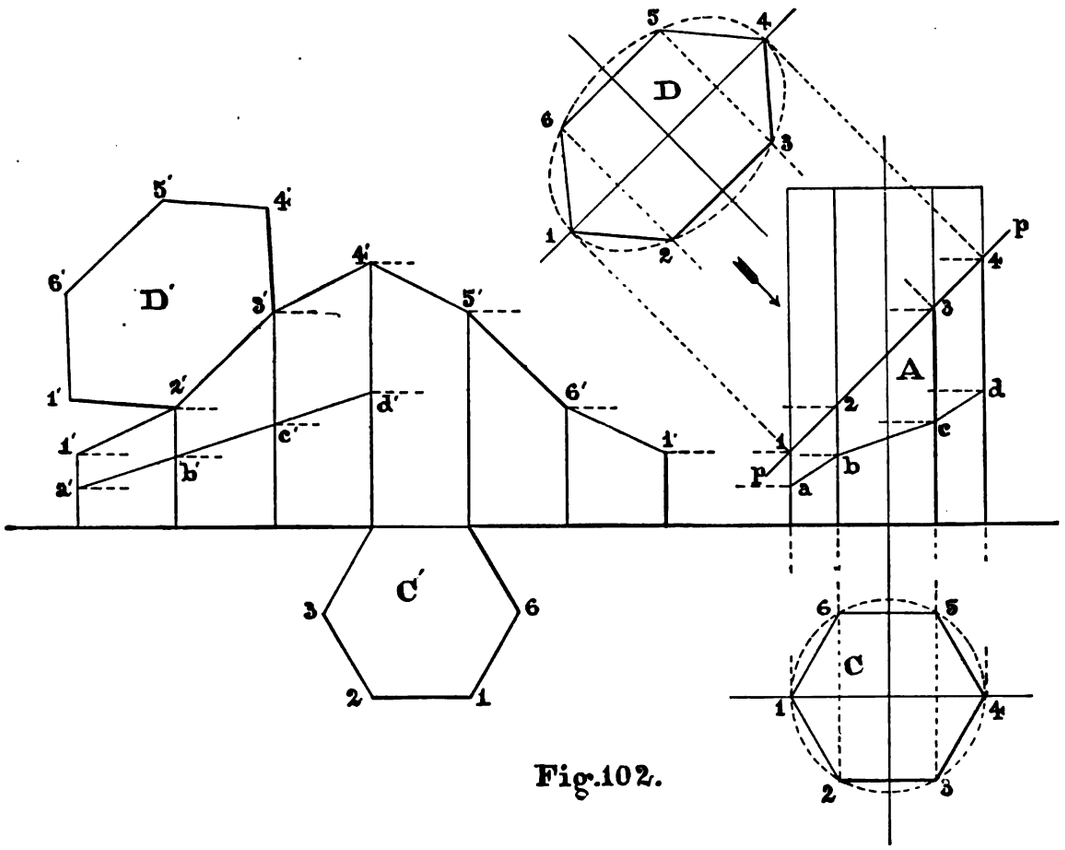

Fig. 102.

seen directly in the front view *A*, and it is self-evident that the top view *C* is not affected in any way.

The true form of the section will be seen by constructing a view, *D*, looking perpendicularly against the plane *pp*, as shown by the arrow. In this view the line 1–4 will appear of its true length and parallel to *pp*; and the lines 2–6, 3–5 will be perpendicular to 1–4, and also appear of their true length, which is seen in the top view *C*. Having located the points thus indicated, the contour of the section will be an irregular hexagon.

166. Now suppose the upper part of the prism to be removed, and the lower part to be formed of thin sheet-metal. Let this be cut vertically along the edge 1, and unfolded into a plane. Since the edges of the lower base lie and remain in the horizontal plane, they will extend themselves into one right line, whose length is equal to the perimeter of the base *C*, that is, to six times one of the sides. Thus, in the development shown at the left, the edges will be represented by equidistant vertical lines, and the lengths of these lines will be the same as in the front view *A* of the truncated prism. The upper extremities of these verticals are joined by right lines, which completes the development of the vertical surface of the prism. If desired, *D'*, a copy of *D*, and *C'*, a copy of *C*, may be attached as shown: the entire outline thus formed being cut out of card-board, and the lines of junction being cut half through the thickness with a sharp knife, the whole may be folded up into a very satisfactory model.

167. Let it be required to find the shortest path on the vertical surface of the prism, from the point *a* to the point *d*. In the development these points fall at *a'* and *d'*; the least distance between them is the right line *a'd'*, which cuts the edges 2' and 3' at *b'* and *c'*; project these back to the original positions of those edges in view *A*, and the broken line *abcd* represents the path required.

This problem of "the shortest path" may be similarly treated in the case of any solid whose surface is capable of development into a plane, provided that in the development a straight line can be drawn between the two points.

168. If we imagine the prism in Fig. 102 to be inscribed in a circular cylinder, the circle which circumscribes the hexagon in the top view *C* will be the base of that cylinder, the edges of the prism will be vertical elements, and the true form of the section will be the ellipse shown in a dotted line in view *D*; also, the development of this section will be a curve passing through the points 1', 2', 3', etc., of the development of the prism.

In order to define these curves more accurately, it is necessary only to divide the circumference in the top view into a greater number of parts, and by thus increasing the number of elements, as shown in Fig. 103, to locate more points in the curves. The details of the process have already been explained in connection with Fig. 90, and need not be repeated. Also, it was shown (**149**) that the "shortest path" between two points on the surface of the cylinder is in general a helix. That is to say, a helix drawn upon a cylinder develops into a right line when the cylinder is unrolled into a plane.

169. Conversely, if an oblique right line is projected upon a cylinder, its development on unrolling the cylinder will be the projection of a helix. Thus in Fig. 103, *ab* represents such a line projected upon the cylinder in the front view *A*; draw in the development the horizontal line *a'a''*, and through *b'* a line *ll* parallel and equal to it: then the curve *a'b'a''* is the projection of a helix whose pitch is *a'a''*, lying upon a cylinder whose diameter is *a'l*, the axis

being the horizontal *xx* passing through 3 in view *A*. Moreover, the tangent *tt* at 3″ is parallel to *ab* or *pp*. The precautions and expedients mentioned in relation to the drawing of the helix therefore apply as well to the drawing of this development of the section of a cylinder by a plane.

Since the ellipse is perfectly symmetrical about both axes, it may be turned end for end; and the two parts of a cylinder thus cut by a plane making an angle of 45° with the axis may be joined together as at *V*, making what is known as a "square elbow." By using other

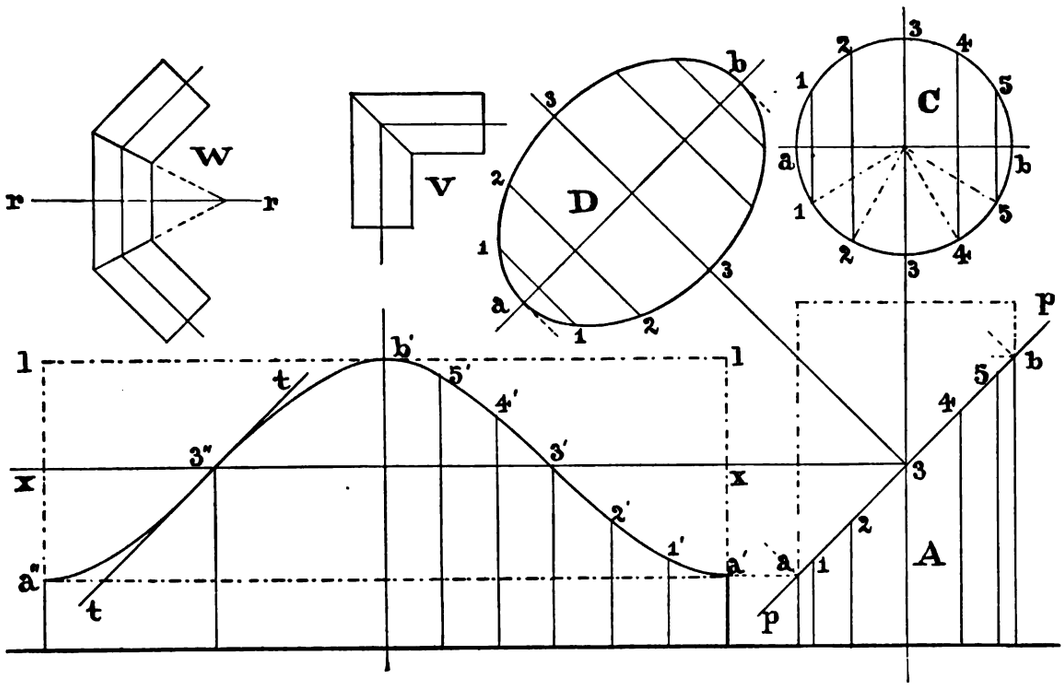

FIG. 103.

angles, the pieces may be put together at different inclinations, as shown at *W*, which represents a "three-section elbow." To lay out the sheet for the middle piece, cut it transversely by a plane *rr*: the circle will develop into a right line, and the ordinates are measured each way from this in order to determine the contour.

170. In Fig. 104 the hexagonal pyramid is cut by the plane *pp*. The top view of the section is an irregular hexagon, determined by projecting the points 1, 2, 3, etc., of the front view *A* vertically downward to the corresponding edges in view *C*; after which the view *D* is constructed exactly as in the case of the prism, Fig. 102.

In the development the vertex of course remains a point; and since the edges of the pyramid are of equal length, their lower extremities will lie in the circumference of a circle whose centre is *v'*, and radius *v'n'*, equal to *vn*: the chords *n'm'*, *m'r'*, and so on, are equal to each other and of the true length, *nm*, *mr*, of the edges of the base.

The true distances of the points 1 and 4 from the vertex are seen in view A; therefore in the development $v'1' = v1$, and $v'4' = v4$. But while vm is actually equal to vn, it is foreshortened in view A. All parts of it are, however, foreshortened in the same proportion; therefore drawing through 2 a horizontal line cutting vn, we have $v2''$ as the true distance from 2 to the vertex, and the true length of $v3$ is found in like manner. Therefore set off $v'2' = v2''$, $v'3' = v3''$, and the broken line $1'2'3'4'$ is the development of the section of the pyramid.

The representation of the shortest path from a to d is found by reversing this process: the right line $a'd'$ cuts $v'm'$ and $v'r'$ in b' and c'; set off vb'', vc'', respectively equal to $v'b'$,

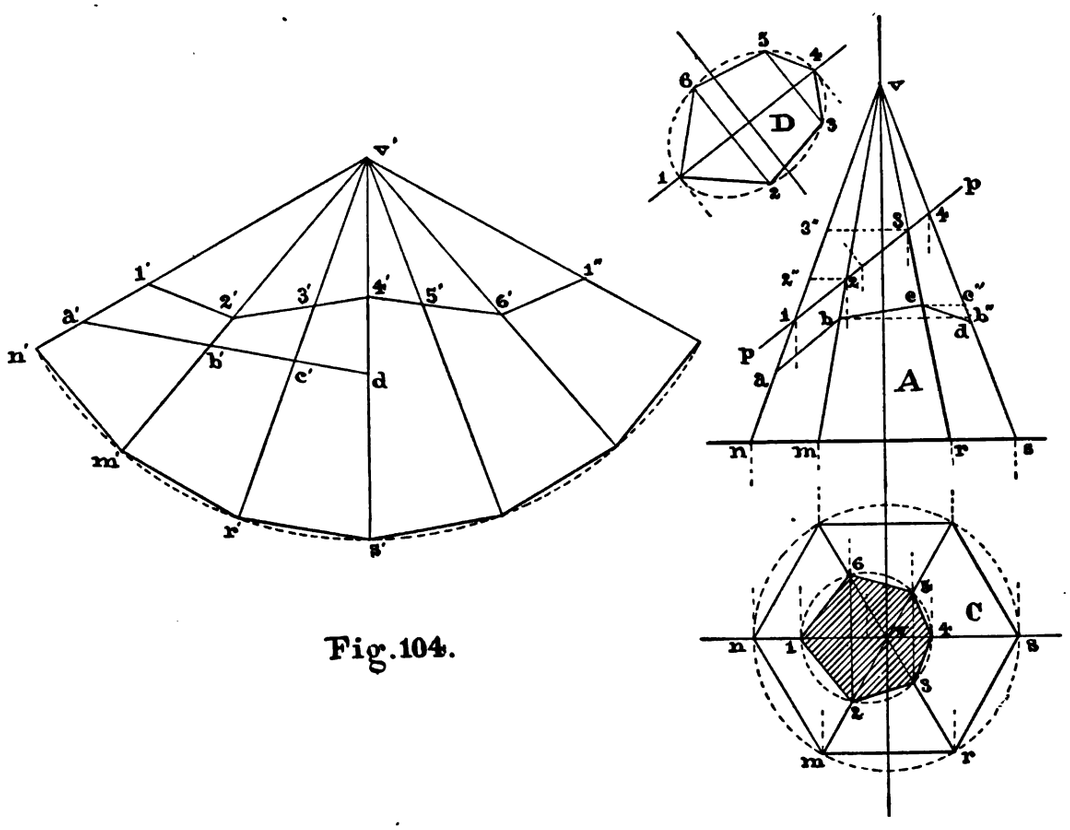

Fig. 104.

$v'c'$, on vs, and draw horizontals through b'' and c'' to locate b and c: then the broken line $abcd$ is the path required, which will also be visible in the top view.

171. If a cone be circumscribed about the pyramid, its base will be the dotted circle in the top view of Fig. 104, and the edges of the pyramid being rectilinear elements of the cone, the true form of the section will be the dotted ellipse in the view D: this section will also be projected as an ellipse in the view C, and in the development will form a curve passing through the points 1′, 2′, etc.

The construction in the case of the cone is shown in Fig. 105: if we draw any rectilinear elements, as *vm*, *vr*, they will be cut by the plane at points 1, 2, seen directly in the front view, whence they may be projected to the top view. But in this top view these projecting lines will cut the elements very acutely in the neighborhood of *vs*, so that the curve cannot thus be very accurately defined. In this region another process is preferable: suppose the cone cut across transversely by a plane *lf*; the section will be a circle, which may be drawn in the top view. Since the planes *lf*, *pp* are both perpendicular to the paper in the front view, the point *q* represents their intersection, which in the top view will be seen in its true

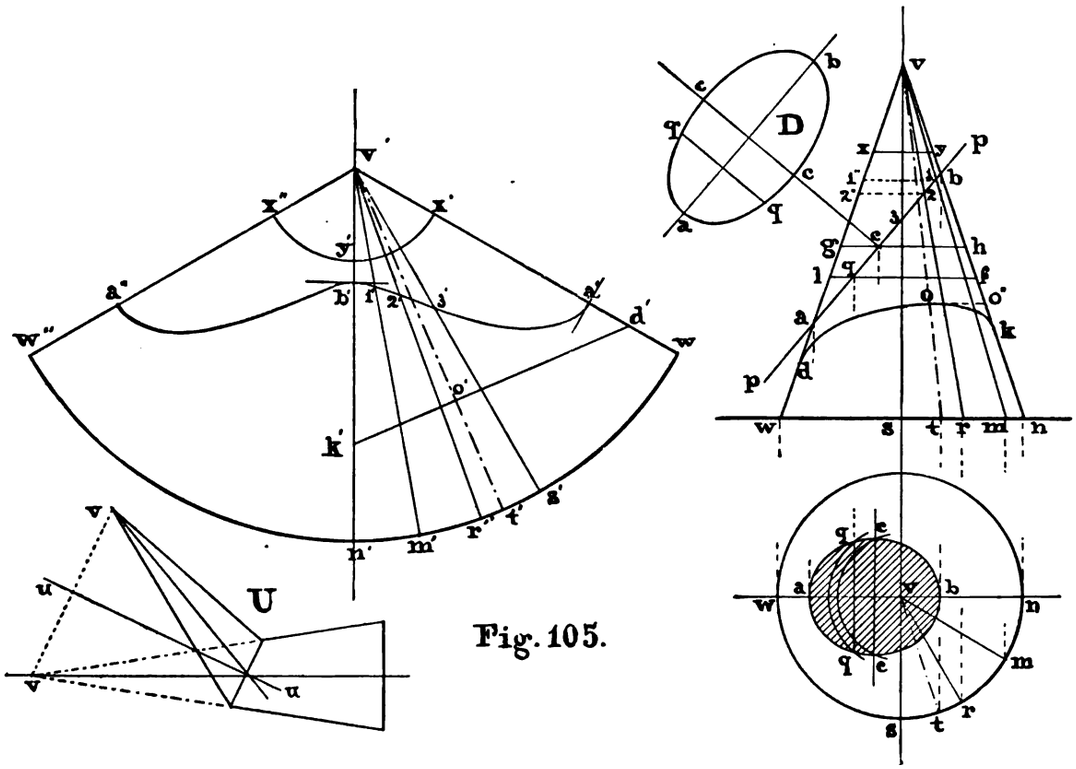

Fig. 105.

length as a chord *qq* of the circle just drawn. This operation may be repeated as many times as is necessary: and it is needless to say that any such chord will also be seen in its true length in the view *D*.

172. Since the section of the cone by the plane is known to be an ellipse (when, as in this case, all the elements are cut), it is perfectly legitimate to determine the axes, and construct the curve by any convenient method. It is clear that *ab* in the front view is the length of the major axis in the view *D*; to determine the minor axis, bisect *ab*, and pass a horizontal plane *gh* through the point of bisection, by means of which find the chord *cc* in the top view as just explained: this will be the minor axis of the ellipse seen in the top view, as well as of the true elliptical section *D*.

It is clear that, as in the case of the cylinder, the ellipse may be turned end for end, and the upper part of the cone joined to the lower, as in the small diagram U; the vertex going from its original position v to the new one v', by revolving around an axis uu, perpendicular to the plane of the ellipse at its centre.

173. The developed surface of the entire cone will be limited by two rectilinear elements, including a circular arc whose radius is the slant height, and of a length equal to the circumference of the base. Having described with that radius an indefinite arc about v', lay off upon it, by the process of Fig. 34, an arc equal in length to a convenient fraction of the circumference of the base, rectified as in Fig. 33, and step this off the required number of times, to determine $w'n'w''$: this done, points in the curve $a'b'a''$ are located precisely as in the case of the pyramid, Fig. 104. In relation to this, it is to be particularly noted that as the tangents to the ellipse at a and b are perpendicular to the elements through those points, so the tangents to the developed curve are perpendicular to $v'a'$, $v'a''$, $v'b'$.

The "shortest path" from d to k is determined exactly as in the case of the pyramid. Since in the development $d'k'$ cuts both $v'w'$ and $v'n'$ obliquely, it is to be observed that in the front view the projection of this path will be tangent to vw at d, and to vn at k. The highest point of this projection may be found as follows: The least distance of $k'd'$ from the vertex is the perpendicular $v'o'$ let fall from v' in the development; set off $vo'' = v'o'$, on vn in the front view, and a horizontal through o'' will be tangent to the path at its highest point. Produce $v'o'$ to t', rectify the arc $n't'$, and set off an arc nt of the same length in the top view; project t to the line of the base in the front view: then tv will be the element corresponding to $t'v'$ in the development, and will cut the horizontal through o'' in o, the required point of tangency.

174. These problems of development are of direct practical use to the workers in sheet-metal. Thus if the cone be cut off by another horizontal plane xy, the frustum $wxyn$ forms the body of a funnel; if in Fig. 103 the plane pp cuts the elements of the cylinder at an angle of 45°, the two portions of the solid may be joined to form the "square elbow" V; and the development is the shape of the metal sheet from which each piece is made. By using other angles, the cylindrical pieces may be joined as at W in Fig. 103; in this case an imaginary right section at rr will develop into a right line, and by measuring each way from this the contour is determined.

Theoretically, it makes no difference along what element the cylinder or cone is cut: but practically it should, when there is no reason to the contrary, be cut *so as to form the shortest seam.*

Again, the drawing of a bevel-wheel involves the development of a cone, upon which the outlines of teeth are laid out; the correct representation of the teeth of the wheel depending upon the forms which these outlines assume when the developed sheet is re-formed into its original cone.

175. It will be understood from the preceding examples that in the development of a surface by unfolding or unrolling it into a plane there is no extension or compression, or distortion of any kind. Lines of course change their forms, but not their lengths: if they intersect on the original surface, they will after development intersect at the same angle; if, on

the other hand, they are originally tangent, they will remain tangent. The surfaces of solids bounded by planes are developed by unfolding, the various faces turning upon the edges as upon hinges; the surfaces of cylinders and cones, as we have seen, are developed by unrolling, the only difference being that the number of edges is infinite. These are the only curved surfaces commonly met with that are capable of development; but there is a third kind, of which a single example will be sufficient.

176. It is a familiar fact that if a piece of paper in the form of a right-angled triangle, as $AA'B'$, Fig. 90, be wound around a cylinder so that the base of the triangle forms the circumference of the base of the cylinder, the hypothenuse will form a helix: thus AB' of Fig. 90 becomes the helix $A369B$ of Fig. 89. In Fig. 106 the paper is shown as partly unwound; bm being equal to the quadrant $a'c'$ of the base, it is apparent that the hypothenuse bc is tangent to the helix at c, and equal in length to the helical arc ac. It is clear that as the unwinding progresses the point b will trace in the plane of the base the involute $a'b'r'$ of the circumference; the upper edge of the paper will in every position be tangent to the helix, and these different tangents must lie upon a continuous surface, of which a limited portion is represented in Fig. 107. It will be recognized that this surface somewhat resembles that of a cone; but as the elements, instead of meeting in one point, are tangent at various points to the helix, the surface goes on, expanding as it rises, and winding about the cylinder in convolutions like those of a sea-shell.

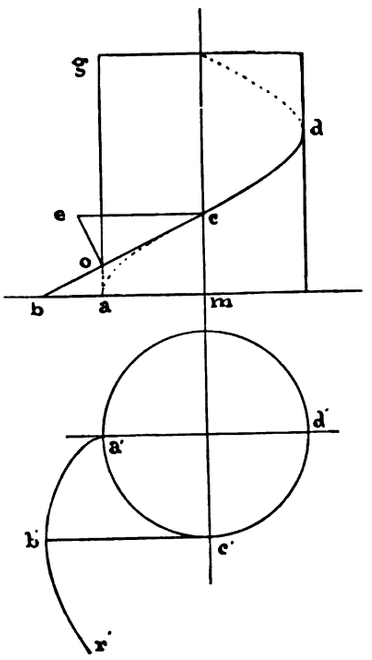

FIG. 106.

177. The helix itself, winding equably around the cylinder, has everywhere the same curvature. In Fig. 106 bc cuts ag, the projected outline of the cylinder, at o; draw at this point a perpendicular to bc, cutting at e a horizontal line through c: then ce is the radius of curvature of the helix acd.

Ascertain in this way the radius of curvature, cy, of the helix in Fig. 107; and about any point O, Fig. 108, describe a circle with this radius. If then the helix be supposed to be made even of wire having a sensible thickness, a portion of it equal in length to the circumference of this circle can "have the twist taken out of it," and be made into a ring which will lie flat on the paper; and all the tangents to the helix will also lie in the same plane, and be tangent to the circle. Since the length of each tangent, in the formation of the surface, was equal to that of the helical arc from which it was unwound, and remains the same after the development, the involute $a'b'f'$ in Fig. 107 will become the involute of the new circle in Fig. 108. Making the tangent AH in this figure equal in length to the circumference, then, the piece $AHGFBA$ may be cut out of paper or thin metal, and (the circle being also cut out) it can be bent up, the circumference fitting the helix $acde$ in Fig. 107, the curve $ABFG$ at the same time contracting into the involute $a'b'f'g'$, and thus the plane will assume the form of the

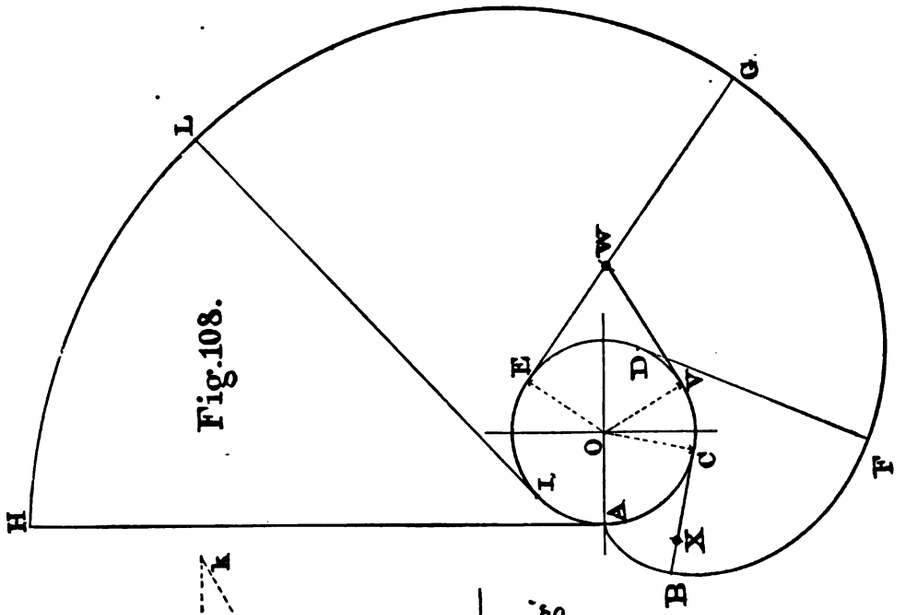

Fig.108.

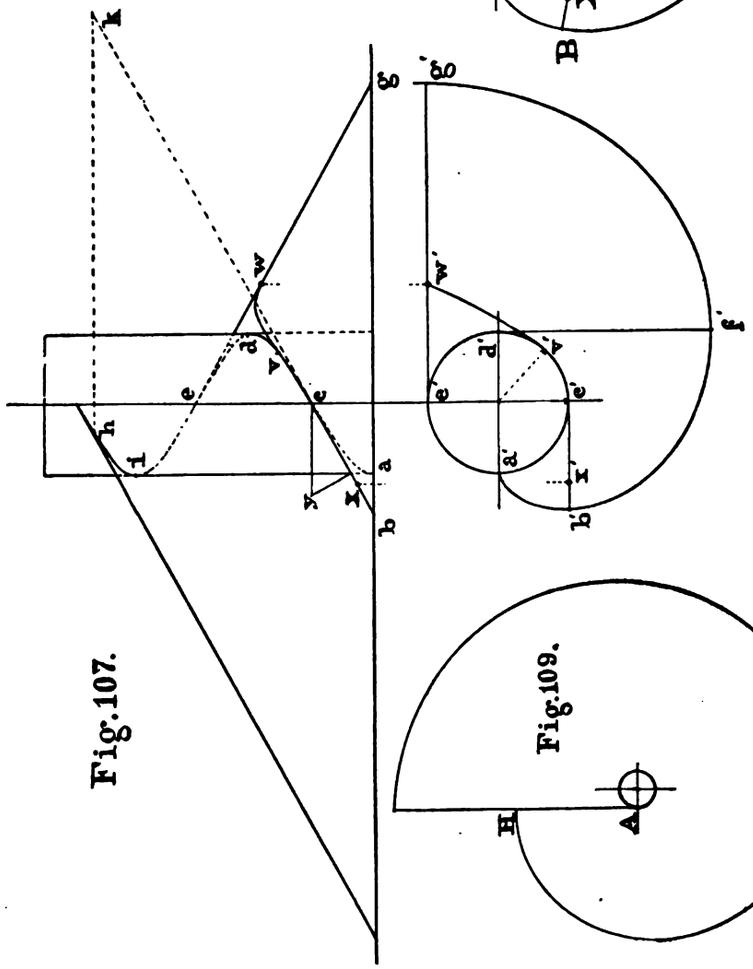

Fig.107.

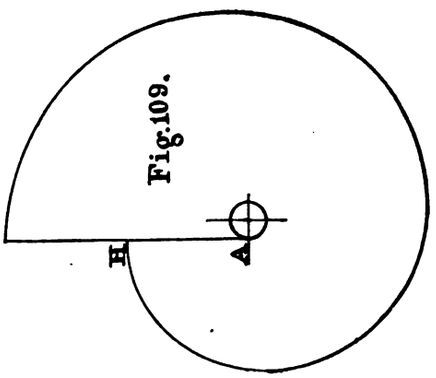

Fig.109.

original surface. Produce *bc* in Fig. 107, set off $bk = AH$, and draw a horizontal through *k*, cutting the helix in *h*, which will be the limit to the height of the part of the surface of which Fig. 108 is the development. No more than this can be cut out of a single sheet; but since the edge *HA* is lifted out of the plane in forming up the surface, another piece, shown on a smaller scale in Fig. 109, can be joined to the first one along that edge, and so on indefinitely.

178. Let it be required to find the shortest path upon the surface from *x* to *w*, in Fig. 107. Since *x* lies upon *bc*, its position *X* in Fig. 108 will be upon the corresponding tangent; make *AC* equal to the helical arc *ac*: then the tangent *CB* is the one required. Similarly, make *ACDE* equal to the helical arc *acde*: then the tangent *EG* is the position of *eg* in the development, and upon it *W* is located.

We now find that a straight line cannot be drawn upon this development from *X* to *W*, because such a line would cross the circle, within which the surface has no existence, thus presenting a singular exception to the general rule. Draw *WV* tangent to the circumference: then the shortest path is composed of the two tangents *XC*, *VW*, and the circular arc *CV* between the two points of tangency.

On the original surface, then, this path is made up of the portion *xc* of the element passing through *x*; of the portion *cv* of the helix; and of a curve *vw* tangent to the helix,—which can be constructed by drawing in Fig. 108 tangents to the arc *VE*, as *DF* for instance: these are the developed positions of elements, and cut *VW* in points which, when they are restored to their original locations on the surface, lie upon the required line.

179. From the preceding examples it will have been gathered that in order to construct the intersection of a surface with a plane it is necessary to find the points in which the plane cuts a series of lines drawn upon the surface: and it is clear that these lines should be the simplest that the nature of the case will admit of, unless the intersections are too acute to give reliable determinations; which may happen, as we have seen in the case of the cone, when the rectilinear elements alone are depended on. Also, it will be noted that the object and the plane are represented in such a position that in one of the views the plane is seen edgewise: this greatly facilitates the construction, and exhibits most clearly the reason for each step. If after the section is made a view of the object from any other direction or in any other position is needed for any reason, it can readily be made by the processes explained in Chap. IV.

180. Fig. 110 represents a solid of revolution; that is to say, one that can be turned in the lathe; every transverse section is a circle, which in general is the simplest line that can be drawn on such a solid.

In determining the intersection of this object with the plane *pp* these circles are made use of precisely as in the case of the cone (**171**). Thus the point *a* in the front view represents a chord in the circle whose radius is *ik*, and this chord is seen in its true length in the top view and also in the view *D*, which shows the exact outline of the section. So, again, *c* and *d* in the front view represent the chords *cc*, *dd*, in the circle whose radius is *lm*: *e* in the front view coincides with *d*, but represents a chord *ee* of the circle whose radius is *ln*, *n* being the point at which the curved outline of the base of the object is tangent to the prolongation of the

horizontal line *lm*. Thus, since the upper side of the base has a narrow *plane* ring whose breadth is *mn*, the small portions *de*, *de* in the section are straight lines.

It is hardly necessary to point out that in actually constructing the section very small arcs only of the circles used need be drawn, and the chords should not be drawn at all, the extremities alone being marked.

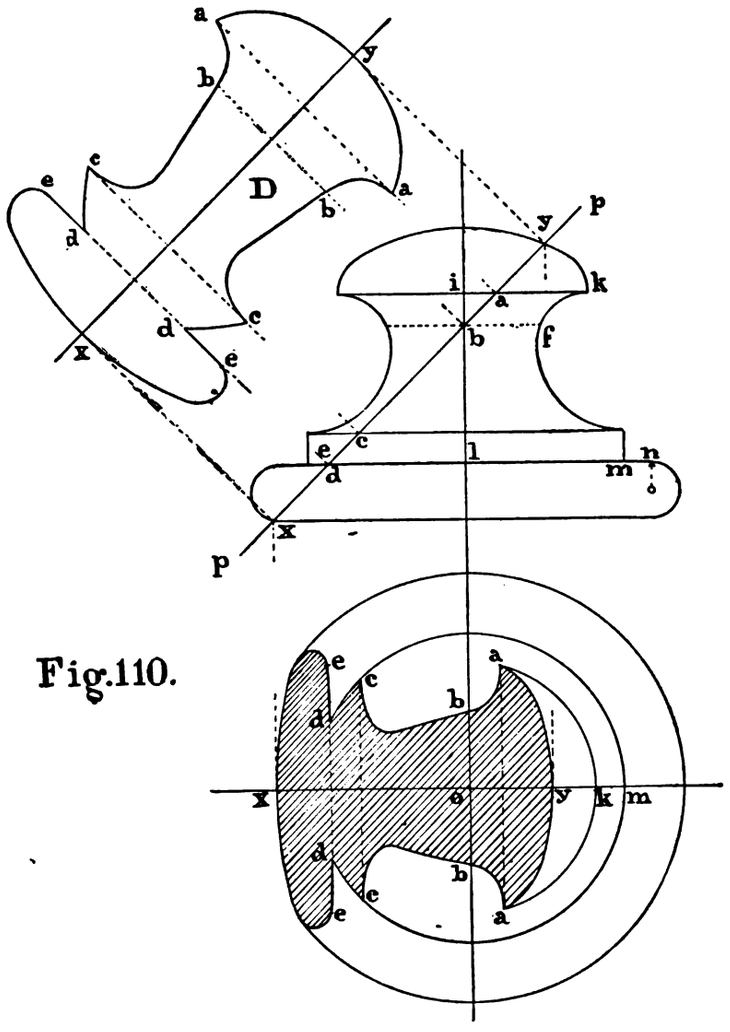

Fig. 110.

181. Fig. 111 represents also a solid of revolution, whose outline *gif* is an hyperbola whose conjugate axis *ll* is the axis of the solid. It may also be formed by the revolution about the same axis of the two lines *aob*, *cod*, which in the front view coincide with the asymptotes: these are in this view parallel to the paper, and in the top view coincide in one line $a'b'$, the distance $l'o'$ being equal to *io*, the semi-major axis; in the side view *B* they also coincide in one line *bc*, and obviously they determine a plane parallel to *ll*, which, while cutting these two lines out of the surface, is also tangent to it at the point *o*.

It is apparent that the point *b* describes the circle of the lower base, whose radius is *l'b'*; also that *o* describes the *circle of the gorge*, *ii*, its radius *l'o'* being also taken directly from the top view. Every intermediate point on *ab* follows the same law, so that if this line and the axis are given or assumed, the hyperbolic outline is most expeditiously drawn by the method of Fig. 48.

The section of this surface by an inclined plane *pp* which cuts all the elements is an ellipse, of which the major axis is *xy*. Bisect *xy* at *r*; a transverse section through this point

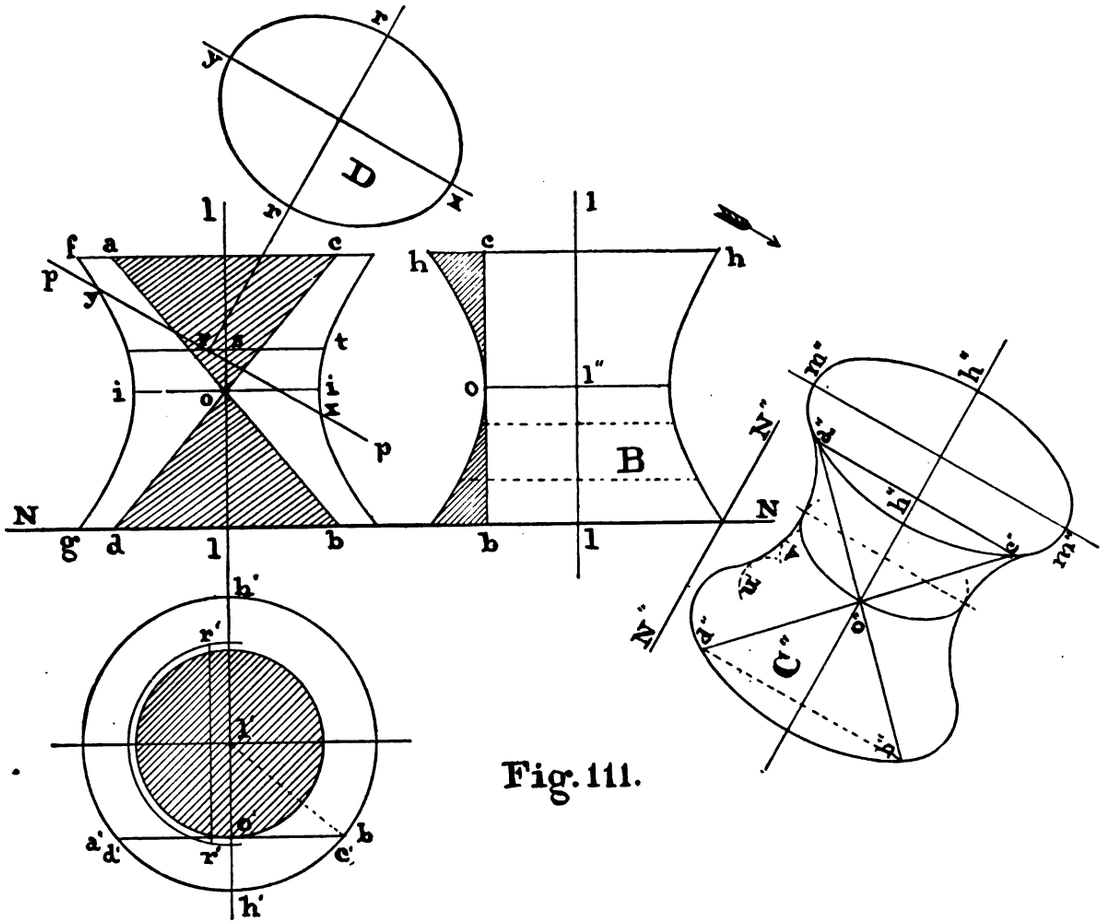

Fig. 111.

is a circle with radius *st*, in which *r* represents the horizontal chord *r'r'* in the top view, and this is the minor axis; from which data the view *D* is constructed directly.

182. Drawing a new base-line *N''N''*, let it be required to make a view *C''*, looking perpendicularly down upon the new horizontal plane thus indicated, as shown by the arrow. The axis will appear as a line parallel to *N''N''*, and the upper base as an ellipse of which the minor axis is *h''h''*, the foreshortened projection of *hh*, the major axis *m''m''* being seen in its true length, that is, equal to *hh*. The lower base will appear as a similar and equal ellipse, and the circle of the gorge as a smaller one, constructed in like manner. So also any inter-

mediate transverse sections will be projected as ellipses, small portions of which are shown at *u*, *v*, and the outline will be limited by a curve tangent to all these ellipses.

This illustrates very clearly an important principle of universal application, viz., that **the visible contour** of any object, in any projection whatever, is **the envelope of all the lines which can be drawn upon its surface.**

183. Fig. 112 represents the "stub end" of a connecting-rod; it is rectangular in section, as shown by *f'kmn* in the end view, and is joined to the cylindrical neck of the rod by the surface of revolution, whose outline *WY* is usually, as here shown, a circular arc. We have, then, to determine the intersections of this surface by two planes *pp*, *rr*, parallel to the axis.

A transverse section at *a* is a circle, which in the end view is seen to be cut by the plane

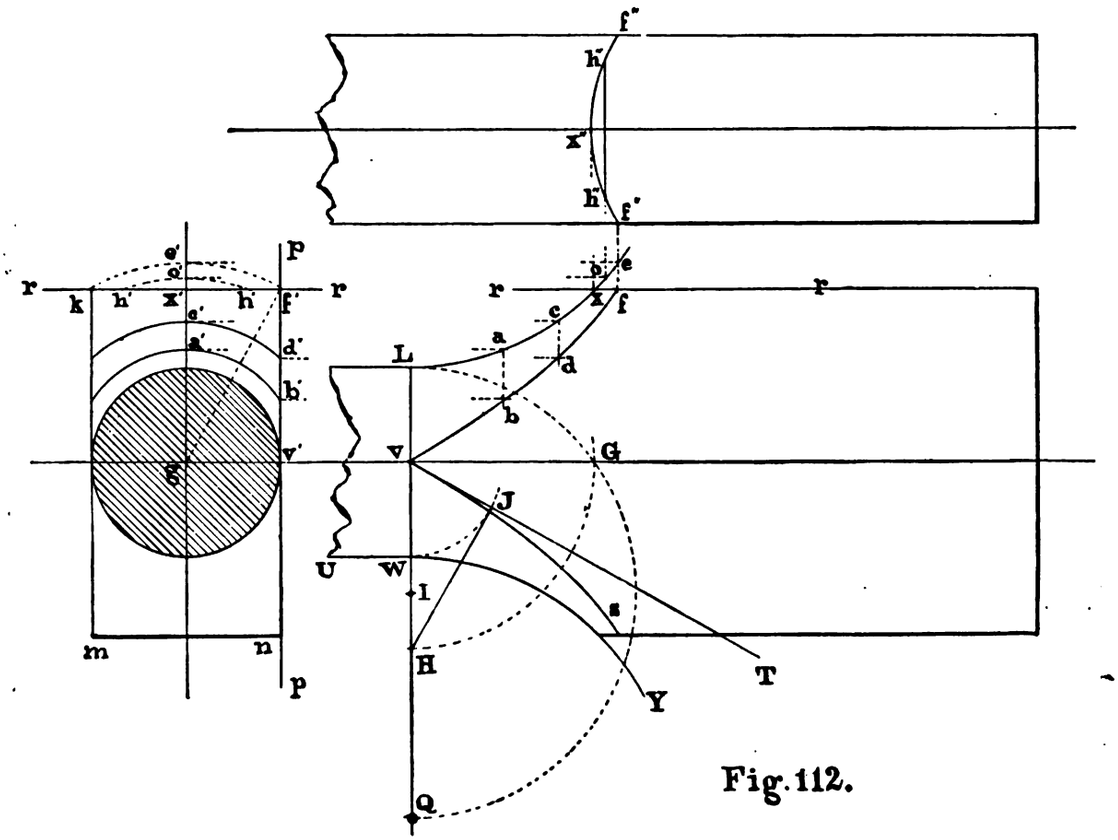

Fig. 112.

pp at *b'*, which is projected back to *b*, a point in the required curve; in like manner the point *d* is located by means of a transverse section at *c*, and so on.

The plane *rr* cuts the outline at *x*, which determines the vertex *x''* of the curve seen in the top view. This plane intersects *pp* in the line forming the upper front edge of the stub end, which appears in the end view as the point *f'*. A circle described about *g* through *f'* cuts the vertical centre-line in *e'*, which, projected back to the contour at *e*, gives the location of a transverse section from which, by the preceding process, would be determined the point *f* in the front view, corresponding to *f''* in the top view. A transverse section at any point as

o, between *x* and *e*, is a circle, in which *h'k'* in the end view is a chord, seen in its true length as *h''k''*, in the top view, perpendicularly above *o*.

184. Fig. 112 represents the case, very common in practice, in which the thickness of the stub end is equal to the diameter of the neck of the rod, so that the plane *pp* is tangent to the neck, as seen in the end view, and also to the concavo-convex surface of revolution at the point *v*. In this case the two symmetrical curves *vbdf*, *vs* intersect acutely at *v*; the angle of intersection may be determined as follows: Let *Q* be the centre of the contour curve *WY*; produce *QW* to *L*, bisect *QL* at *I*, and upon it as diameter describe a semicircle cutting the axis in *G*. On *vQ* set off $vH = vG$; about *v* describe an arc with radius *vW*, and draw *HJ* tangent to it: then *vJT*, perpendicular to *HJ*, is tangent to *vs* at *v*.

If the stub end is thicker than the neck of the rod, the intersection by the side plane will be a continuous curve, as *fvs* in Fig. 113, which will have a vertical tangent at *v*, and will

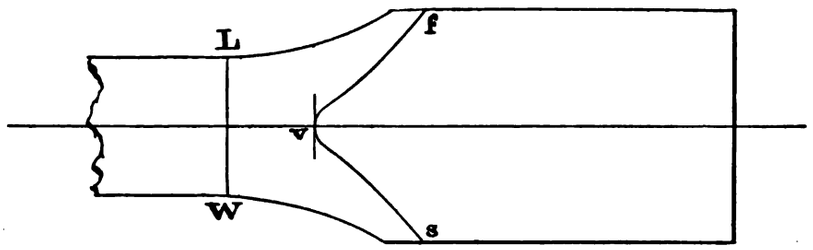

FIG. 113.

usually have a point of contrary flexure, as here shown; the case is analogous to that presented by the plane *rr* in Fig. 112, and requires no farther explanation. If the section of the stub end be square, as it sometimes is, the curves on all four sides will of course be exactly alike.

185. Approximate Developments.—It has already been pointed out that only surfaces of single curvature, such as the cone and cylinder, are capable of development: a warped or twisted surface like that of a screw, or a double-curved one like that of an egg, cannot be transformed into a plane without distortion. Still, approximations may be made, and are often of use, as in the laying out of maps, and in determining the forms of boards for covering hemispherical domes.

This last may be accomplished in two ways illustrated in Fig. 114. In the first method the boards are laid horizontally, forming zones, represented in side elevation and in plan in quadrants I. and II., respectively. Let *AB*, in the enlarged diagram on the left, be half the arc measuring one of these zones, and *AC* the thickness of the board. When in place, it is evident that the edge *DB* should coincide with a radius *DL* of the hemisphere, just as *CA* coincides with a radius *CG*. At *C* and *A* draw perpendiculars to *CG*, and on them set off *CF*, *CE*, respectively equal to the arcs *CD*, *AB*, and draw the radial line *FEH*: then *AEFC* is one half of the transverse section of the board.

Let *a* in quadrant I. correspond to *A* in the large diagram: at this point draw a tangent to the outline of the hemisphere, and produce it to cut the axis in *o*; on *ao* set off *ab'*, *ae'*, respectively equal to *AB* and *AE*, and through the points *b'*, *a*, *e'* describe circular arcs with

centre *o*. In the illustration it is assumed that the board is to cover one quarter of the zone: therefore the arc *al* is made equal to the quadrant *al*, *b'k'* equal to the quadrant *bk*, and the length of *e'i'* equal to that of the quadrant *ei*. This gives the approximate development for the inner surface of the board: the breadth of the outer surface, indicated by the exterior lines, is of course equal to twice *CF*.

186. In the second method the hemisphere is covered with boards cut in the form of gores, the edges, when in place, forming meridians extending from the equator to the pole, as shown in plan and elevation in quadrants III. and IV.

To lay out a gore, erect the vertical *r'p'*, equal in length to the quadrant *rp*, and divide

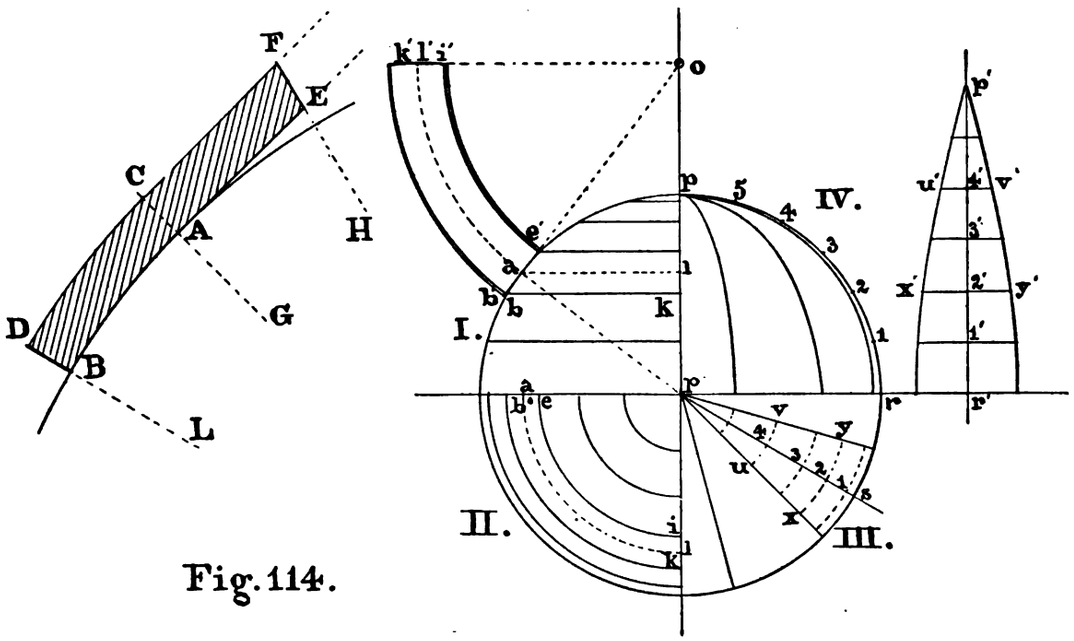

Fig. 114.

it into equal parts, corresponding to the divisions of *rp* by the points 1, 2, 3, etc. In the plan these latter points are for convenience represented upon the bisector *ps*, and through them are drawn circular arcs terminating in the edges of the gore. Then in the development make the horizontal *x'y'*, at 2', equal in length to the arc *x*2*y* in the plan; make *u'*4'*v'* equal to the arc *u*4*v*, and so on: the extremities of these horizontals are points in the contour required.

It need hardly be stated that in the application of either method the zones or the gores, as the case may be, should be narrow, and the boards thin; the breadths have been purposely made much greater than they could be in practice, in order to exhibit the processes clearly: their numbers should be at least four times as great, to give satisfactory results.

INTERSECTIONS OF SURFACES.

187. In Fig. 115 is shown a vertical cylinder, penetrated on the left by an inclined one, the two axes meeting, and on the right by a horizontal one, whose axis is not in the same plane with the other two, but a little in front of that plane.

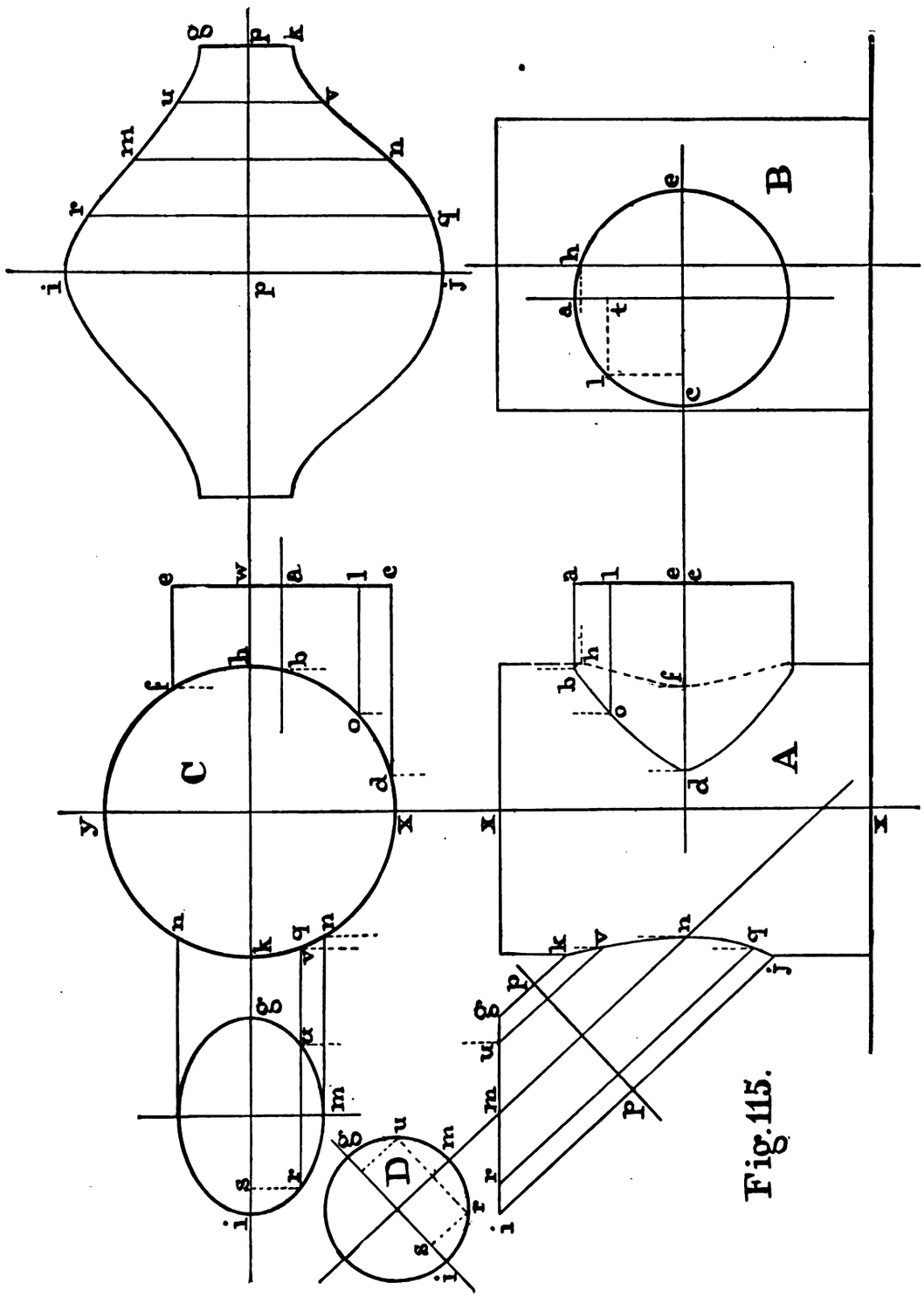
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Fig. 115.

Beginning with the latter, we observe that the point *a* in view *B* represents the line *ab* in views *A* and *C*. And in the top view we perceive that this line pierces the vertical cylinder at *b*, which projected to the front view determines one point in the curve of intersection. Similarly, *c* and *e* in view *B* represent the front and rear elements, and in view *C* these elements pierce the cylinder at *d* and *f*, which projected to view *A* determine the vertices, at which the curve has vertical tangents. If in the top view we draw any element as *lo*, it will be represented in view *B* by a point *l*, whose distance *lt* from the vertical plane through *a* is equal to *la* in view *C*: this determines the height of *lo* in view *A*, to which line the point *o* is projected from view *C*, as before, and so on for as many points as may be required.

Clearly, *b* is the highest point, at which the curve is tangent to *ab*, but it is not the extreme right-hand point, which is found thus: the right-hand element of the vertical cylinder is in view *B* coincident with the centre-line, which pierces the horizontal cylinder in *h*, which projected to view *A* locates the point in question.

188. In the case of the inclined cylinder, the highest and lowest element are at once seen to intersect the left-hand element of the vertical cylinder at *k* and *j*; the nearest element is seen in view *C* to pierce it at *n*, which is projected to view *A*, as before. This inclined cylinder is circular, as shown by the direct end view *D*; being cut off at the upper end by a horizontal plane, the section appears as an ellipse in view *C*. But this does not affect the mode of operation: if we draw upon it in the top view any element as *uv*, the point *u* is projected to *ig* in view *A*, a parallel to the axis is drawn through that projection, to which the point *v* is projected from *C*, thus locating a point in the curve.

Producing *vu* in the top view to cut the ellipse in *r*, it will be seen that there is another element directly beneath *vu*, on the lower part of the cylinder, from which the point *q* is determined in the same way.

189. The development of the inclined cylinder is also shown in Fig. 115. A transverse section at *pp* will be a circle, and will develope into a right line, from which the distances to the points *i, j, g, k, r, q*, etc., will be the same as their distances from *pp* in the front view. In the development *pp* is one half the circumference in view *D*; and to save labor it is advisable to subdivide the semi-circumference into equal parts, and draw in *A* elements corresponding to these points of subdivision; then *pp* in the development is to be divided in the same manner: thus in the illustration the semicircle *img*, view *D*, and its rectification *pp* in the development are each divided into four equal parts. This cylinder being cut along the upper element *gk*, not only is the seam the shortest possible, but the development is bounded by curves principally convex; which is a great practical advantage in cutting out a metal sheet: it is also symmetrical with respect to the vertical *ij*, which greatly facilitates the drawing of the outline.

190. In the development of the horizontal cylinder, shown in the upper part of Fig. 116, symmetry is secured by cutting the pipe along the rear element *ef* in view *C* of the preceding figure: it is not the very shortest, but the difference is not great enough to cause any practical difficulty. In this development *cc*, of course, is equal in length to the semi-circumference *cae* in view *B* of Fig. 115; *a* is the middle point of *ce*; and *cd*, *ab*, *wh*, *ef*, the ordinates of the curve, are equal to the corresponding elements in view *C*, the distance *aw* being equal to the arc *ah* in view *B*.

These ordinates, it is to be understood, are given only for illustration; in practice the proper course is to divide the semicircle *cae*, and its rectification *ce* in the development, into the same number of equal parts, draw corresponding elements in view *C*, and set up the corresponding ordinates of the lengths thus determined, as above advised in reference to the inclined cylinder.

191. In developing the vertical cylinder of Fig. 115, the "shortest seam" would be made by cutting it down along either the right-hand or the left-hand element; but this would lead to the very awkward result that a part of one or the other of the openings would be in one

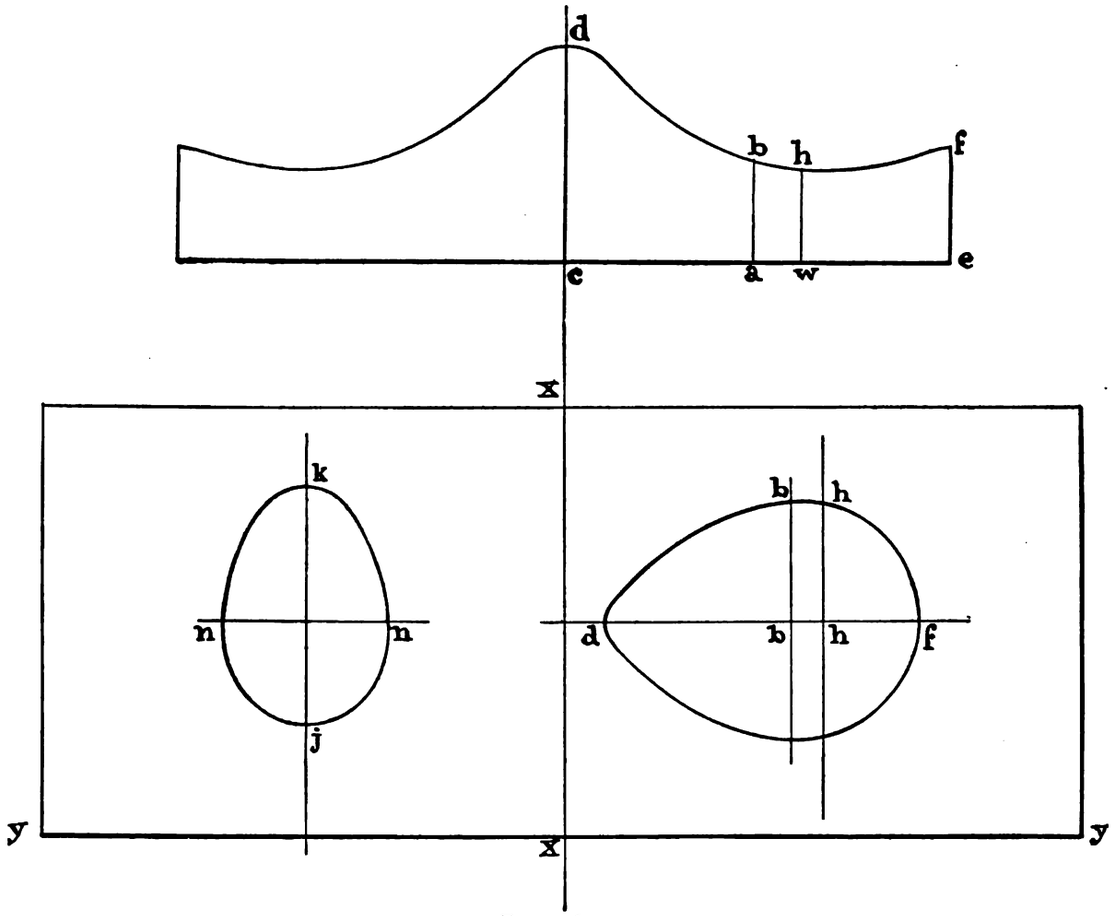


FIG. 116.

end of the sheet, and the remaining part in the other. In the lower part of Fig. 116, then, the development is made on the supposition that the cut is made down the remote element, *y*, in view *C* of Fig. 115, and the cylinder unrolled to the right and left, so that the nearer element *xx* appears as the vertical centre-line. The opening for the horizontal cylinder will then appear on the right, its vertex *d* being at a distance from *xx* equal to the arc *xd*, and its length being equal to the arc *dbf* in view *C*. It will be symmetrical about a horizontal line *df*, at a height above the base equal to that of the axis of the cylinder. The ordinates

of this curve are equal to those of the circle in view *B*: thus, making *db* = arc *dob* in view *C*, the greatest ordinate *bb* is equal to the ordinate at *a*, that is, to the radius; making *bh* = arc *bh* in *C*, set up *hh* = ordinate at *h*, in view *B*, and so on. In making the construction the systematic course previously suggested should be adopted, *df* in the development and the arc *dbf*, being divided into the same number of equal parts, and corresponding ordinates in view *B* being located, just as the one at *l* was from the point *o* in view *C*.

The opening for the inclined cylinder will be on the left, and symmetrical about a

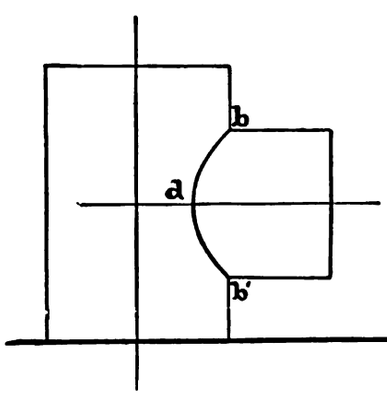


FIG. 117.

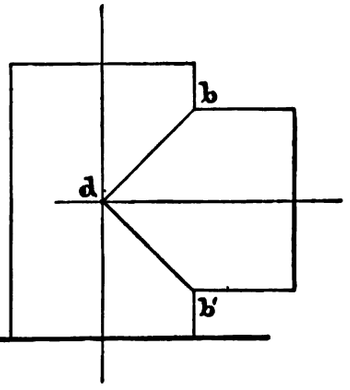


FIG. 118.

vertical line midway between *xx* and the end of the sheet. Its greatest breath *nn* will be equal to the rectified arc *nkn* in view *C*, and the distances of all points in the curve above the base will be the same as in view *A*.

192. If the horizontal axis in Fig. 115 is moved back, nearer to the vertical one, the points *d* and *f* in view *A* will approach each other, *d* moving to the right and *f* to the left, until, when the axes meet, the curves *db* and *fh* will coincide, as shown in Fig. 117; which is a case very often occurring in practice, a familiar example being that of a boiler with a steam-drum. If at the same time the two cylinders are of equal diameters, the intersection will assume the form shown in Fig. 118, being composed of two plane curves *db*, *db'*, each plane making an angle of 45° with either axis; which indeed might have been inferred from consideration of Fig. 103.

If, on the other hand, the horizontal axis be brought forward, the point *d* in Fig. 115 will go to the left, reaching the vertical centre-line when the element *cd* of the horizontal cylinder intersects the element *xx* of the upright one. If the axes be still farther separated, there can no longer be a complete penetration, and the horizontal cylinder must be carried past the other, the effect being shown in Fig. 119. None of these variations involve any new principle, either in determining the intersections themselves or in their development.

193. In Fig. 120 is shown a cone penetrated on the right by a horizontal cylinder, the axes meeting, and on the left by a vertical one, the axes being parallel. In regard to the former, the highest and lowest points, *f* and *g*, of the intersection are seen directly in the front view. Draw in the three views any element *vc* of the cone; in view *B* this is seen to pierce the cylinder at *a* and *b*, which points are projected to view *A*, and thence to view *C*. Draw an element *vq* tangent to the circumference of the cylinder in view *B*; the point of

contact *t* is an important limit to the curve in the other views, in which also it will be a point of tangency.

Otherwise: Any horizontal plane, as for instance the one through *d* in view *B*, will cut an element from the cylinder and a circle from the cone. The circle in this instance has the radius *lh*, and the element is *de*; in view *C* these are seen to intersect in *e*, which is projected to view *A*.

So, too, in the case of the vertical cylinder: the horizontal plane through *o*, for example, cuts from the cone a circle of known radius, which in the top view is seen to pierce the cylinder at *i*, which is projected to the horizontal through *o* in view *A*. Or had an element *vr* been drawn in view *C*, piercing the cylinder in *i*, the same point would have been located

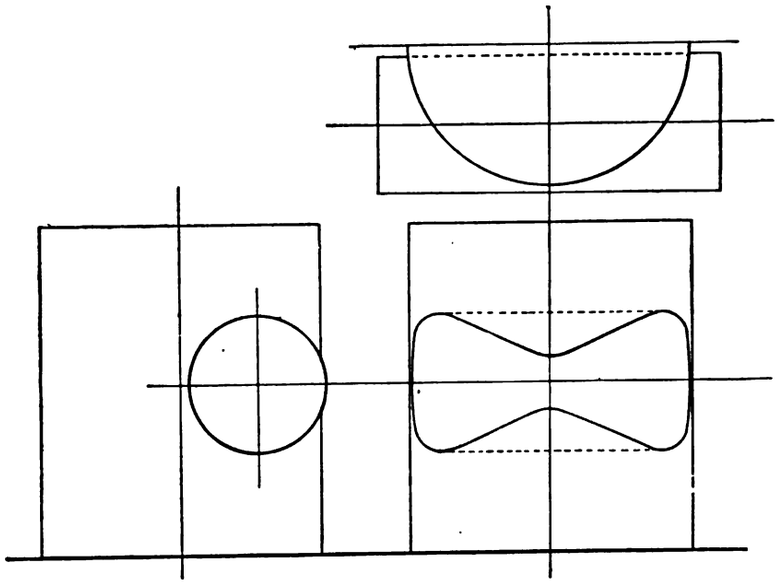


FIG. 119.

by projecting *i* from *C* to *vr* in view *A*: as it should by this time have been perceived that if a point lies upon any line, its projections must lie upon the corresponding projections of the line. Here too a limit is found by drawing an element *vp* of the cone tangent to the circumference of the cylinder in view *C*: the point of contact *s* is then projected to *vp* in view *A*.

194. Let the cone be cut along the remote element, *vx'* in view *B*: then in the development, shown at the right, the arcs *xx'*, *xx''* are each equal to half the circumference of the base, and are bisected by *vm*, *vn*, about which the openings are symmetrical. The arcs *mrp*, *ncq* are equal to the corresponding arcs in view *C*. The vertices *f*, *g* are set off by direct measurement of *vf*, *vg*, in view *A*; the points *a*, *b*, *t* are placed at their true distances from the vertex, *va'*, *vb'*, *vt'* in view *B*. The developed opening for the vertical cylinder is laid out in a similar manner; in regard to this it may be noted that a check upon the accuracy of the work is found in this, that the length of the arc *ii'* should be the same in view *C* and in the development. A system like that previously recommended is applicable to this and all similar cases,—the arcs *mp*, *nq* being divided into equal parts on the circle of the base and also in the development, and intermediate elements drawn through the points of division.

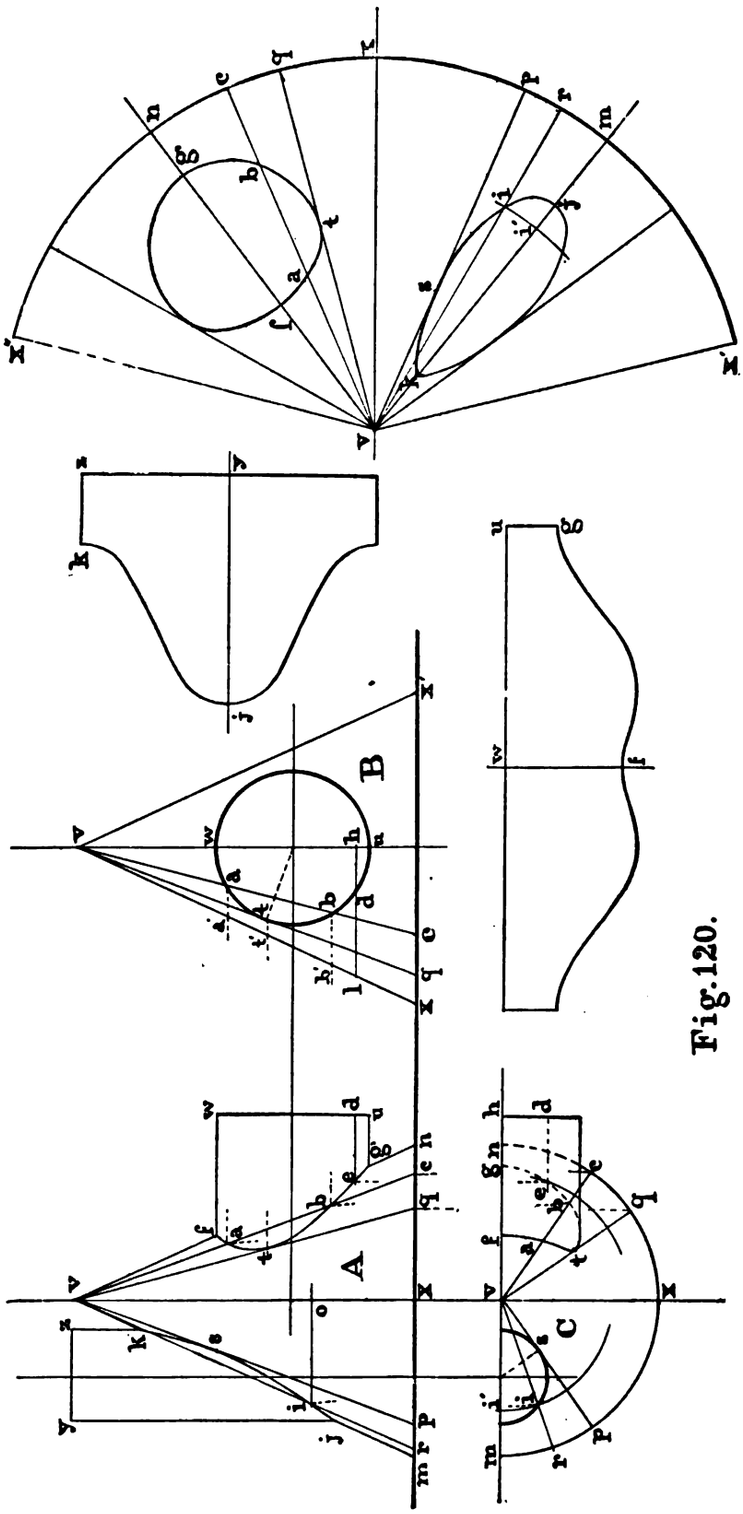


Fig.120.

The developments of the two cylinders are also shown in Fig. 120; they will be at once recognized, and the construction needs no explanation.

195. In Fig. 121 is represented a vertical cylinder intersected by a cone whose axis is inclined and cuts that of the cylinder; the points *f*, *g* of the intersection are at once seen in view *A*.

Extend the cone to any convenient distance within the cylinder, and limit it by a trans-

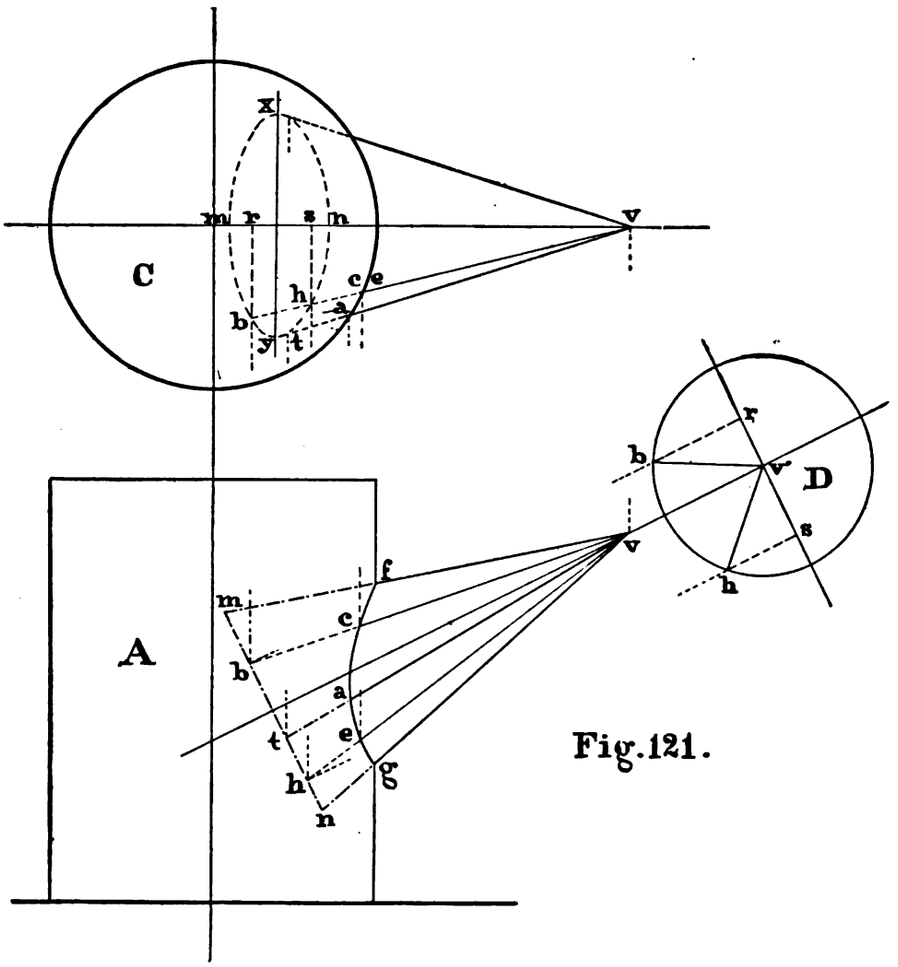


Fig. 121.

verse plane *mn*: the base thus formed is a circle, seen in its true form and size in view *D*, and it is projected as an ellipse in the top view *C*. In this view *C*, the visible contour of the cone is limited by the element *vt* tangent to the ellipse, which pierces the cylinder at *a*. Find the point of tangency *t*, project it to *t* on *mn* in view *A*, in which view draw *vt* and project *a* upon it from view *C*: this gives the left-hand limit of the curve.

Draw any element as *vb* in views *D* and *A*, from the latter project *b* to the ellipse in view *C*; in this view the element thus determined is seen to pierce the cylinder in *c*, which is projected back to *vb* in view *A*. In this way any number of points may be determined; as a

check upon the accuracy, it should be noted that the ordinate *br* is of the same length in views *C* and *D*.

In view *C*, *vb* cuts the ellipse also in *h*, which being projected to *mn* in *A*, shows at once that there is another element *vh* on the lower part of the cone, vertically under *vb*, and piercing the cone at a point *e* vertically under *c*. Or it may be inferred, since the axis of the cylinder is vertical, that a plane through the vertex of the cone, parallel to that axis, cuts two elements from the cone and one from the cylinder; and these lines intersect in points of the required curve.

The process would evidently be the same, were the axes in different planes; commonsense indicating that both should be placed parallel to the paper in the front view. And the

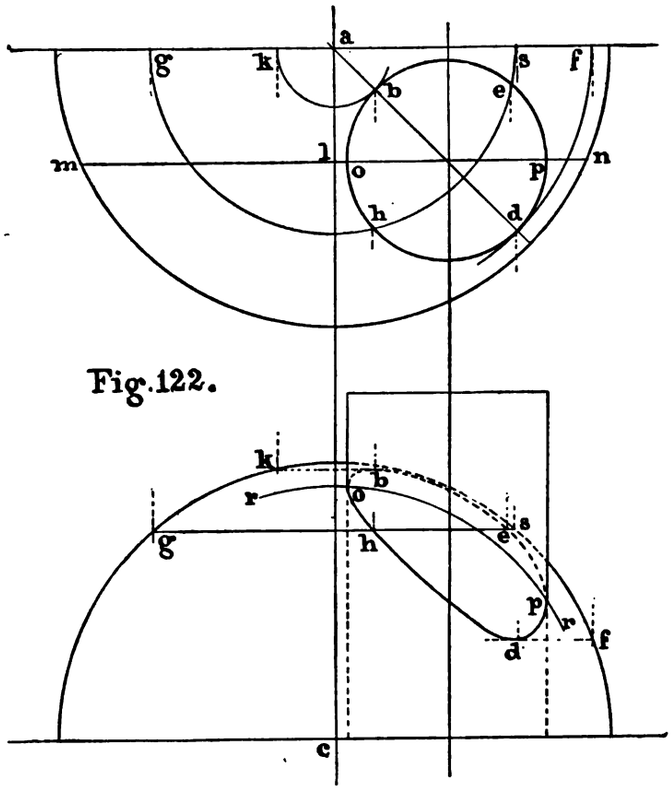


Fig. 122.

development of these surfaces should now present no difficulty to the student, for whose ingenuity the operation is accordingly left as an exercise.

196. Fig. 122 shows a hemisphere penetrated by a vertical cylinder. Any plane parallel to the paper in the front view will cut a circle from the sphere, which in that view will be seen in its true form and size: it will cut the cylinder in two vertical elements if it cuts it at all, and these will intersect the circle in points common to both surfaces. Thus the plane seen edgewise as *mn* in the top view, cuts from the cylinder the extreme right- and left-hand elements, which intersect the circle cut from the sphere, seen as *rr* in the front view, in the points *o* and *p* of the curve of intersection.

Any horizontal plane, as *gs* in the front view, cuts the sphere in a circle, which in the top

view is seen to pierce the cylinder in *h* and *e*, which, projected back to *gs* in the front view, locate two other points in the curve. If in the top view we draw a circle as *df* tangent to the circumference of the cylinder, we can ascertain, by projecting *f* to the outline of the sphere in the front view, the level of the plane by which that circle was cut out, and thus locate *d*, the lowest point of the curve: in like manner the highest point *b* is determined.

197. In Fig. 123 let the two lines *macn*, *oacp* revolve together about the axis *op*. These lines are tangent to each other at *a*, and cut each other at *c*, and will do so throughout the revolution, so that the two circles *ab*, *cd* are common to the two surfaces thus generated.

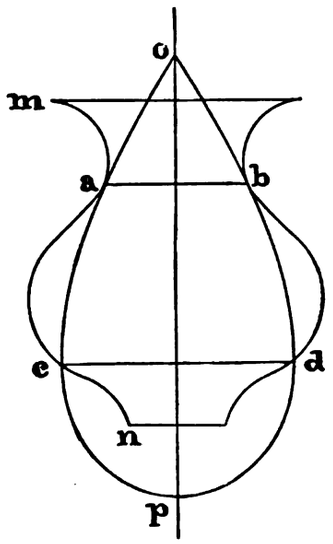


FIG. 123.

Which illustrates a general truth, viz., that if two surfaces of revolution, having a common axis, touch or cut each other at any point, they will do so all round the circle described by that point. In the illustration both the outlines are curved, but clearly either or both might as well have been straight.

The above property may now be applied in finding the intersection of the two surfaces of revolution whose axes intersect, as at *c* in Fig. 124. The simplest lines that can be drawn upon either surface are circles; but if transverse sections are made at random, there is no certainty that the circle thus cut from one surface will intersect the one cut from the other. In order to ensure this, take *c* as the centre of a sphere,—for instance, the one whose outline is *ab*. This cuts from the inclined surface the circle seen edgewise as *oe*; it cuts from the vertical one a horizontal circle through *m*, and the intersection *p* clearly represents a chord common to these two circles, perpendicular to the paper: therefore *p* is in this view a visible point lying on both surfaces, and therefore in the curve sought.

In this case the same sphere serves to locate another point, since *ab* cuts the contour of the vertical surface in *n*, a horizontal through which cuts *oe* in *r*, which also lies upon the required curve. In like manner another sphere whose outline is *gh*, cutting the contour-lines in *k* and *l*, enables us to locate the point *s*; and by repeating this simple operation a sufficient number of times, the intersection of the surfaces may be drawn with great accuracy.

In the ordinary practice of mechanical drawing it is very rarely necessary to construct the top view of an intersection of this nature. Should the occasion arise, however, the student should have no difficulty in doing it: since the radii of the circles through *m*, *n*, etc., are known, it will be seen that the explanations given in connection with Fig. 120 cover the whole ground.

198. In Fig. 125, *v* and *w* are the vertices of two cones of revolution, whose axes, both of which are parallel to the paper in the front view, intersect at *a*. The points *f* and *g* of the curve of intersection are seen by inspection of this view; and other points might be found by means of auxiliary spheres, having *a* for a centre, and cutting circles from each cone, as in the preceding example; but if it is proposed to develop the cones, another method may be preferable.

A plane through the vertex of either cone will cut two elements from it if it cuts it at all; if the same plane passes through both vertices and cuts both cones, the lines cut from one cone will intersect those cut from the other: but any plane through *v* and *w* must contain the line *vw*, upon which the plane turns like a door upon the centre-line of its hinges.

In the application of this it is desirable that the cones should have a common base. The base of the vertical cone is the horizontal plane represented by *NN*, and is a circle whose diameter is *xy*. Produce the inclined cone until *NN* cuts it: the section, or in other words the base of this cone in the same plane, will be an ellipse, whose major axis is *lk*, and this is

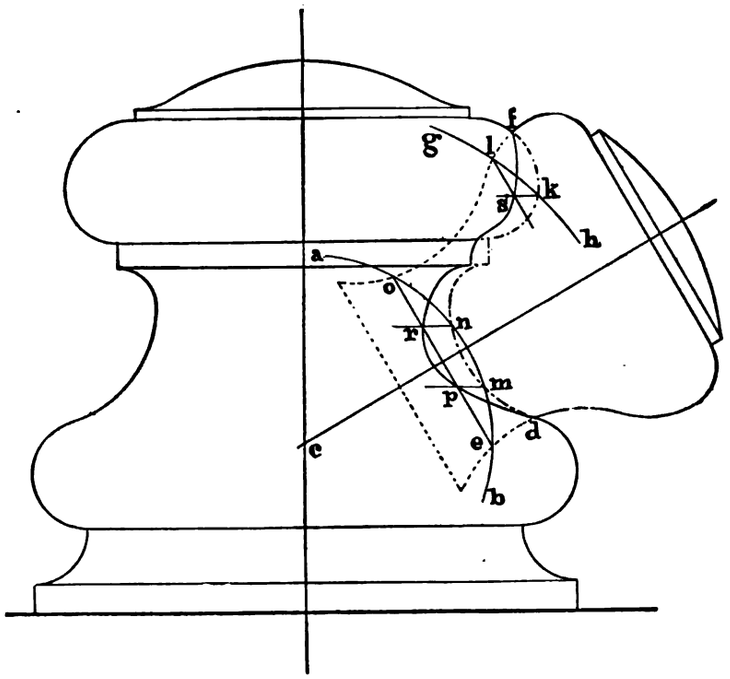


FIG. 124.

readily drawn as in Fig. 105. Produce *vw* until it pierces the plane *NN* in the point *p*. The perspective sketch *Z* shows a cone whose base is in the plane *NN*, and a line *vp* through the vertex, piercing the same plane at *p*; if in that plane any line *pi* be drawn, cutting the base of the cone at *r* and *n*, it will at once be seen that *vp* and *pi* determine a plane which cuts from the cone the two elements *vr*, *vn*; also, if *pj* is drawn tangent to the base at *t*, the plane *vpj* is tangent to the cone along the element *vt*.

198. Now, returning to the principal diagram, draw in the top view the line *pn*, cutting the elliptical base of the inclined cone in *r* and *n*: this determines, as just seen, two elements, *rw* and *nw*. But *pn* cuts the circular base of the vertical cone in *o*, determining in like manner the element *vo*, which cuts *rw* in *c* and *nw* in *d*, and these are two points in the curve of intersection.

A limiting point in this curve is determined by drawing in the top view *pt* tangent to the ellipse, cutting the circular base at *s*. Drawing the elements *tw*, *sv*, they intersect at *b*, at which point *sv* is tangent to the curve, which is clearly shown in the front view: in order

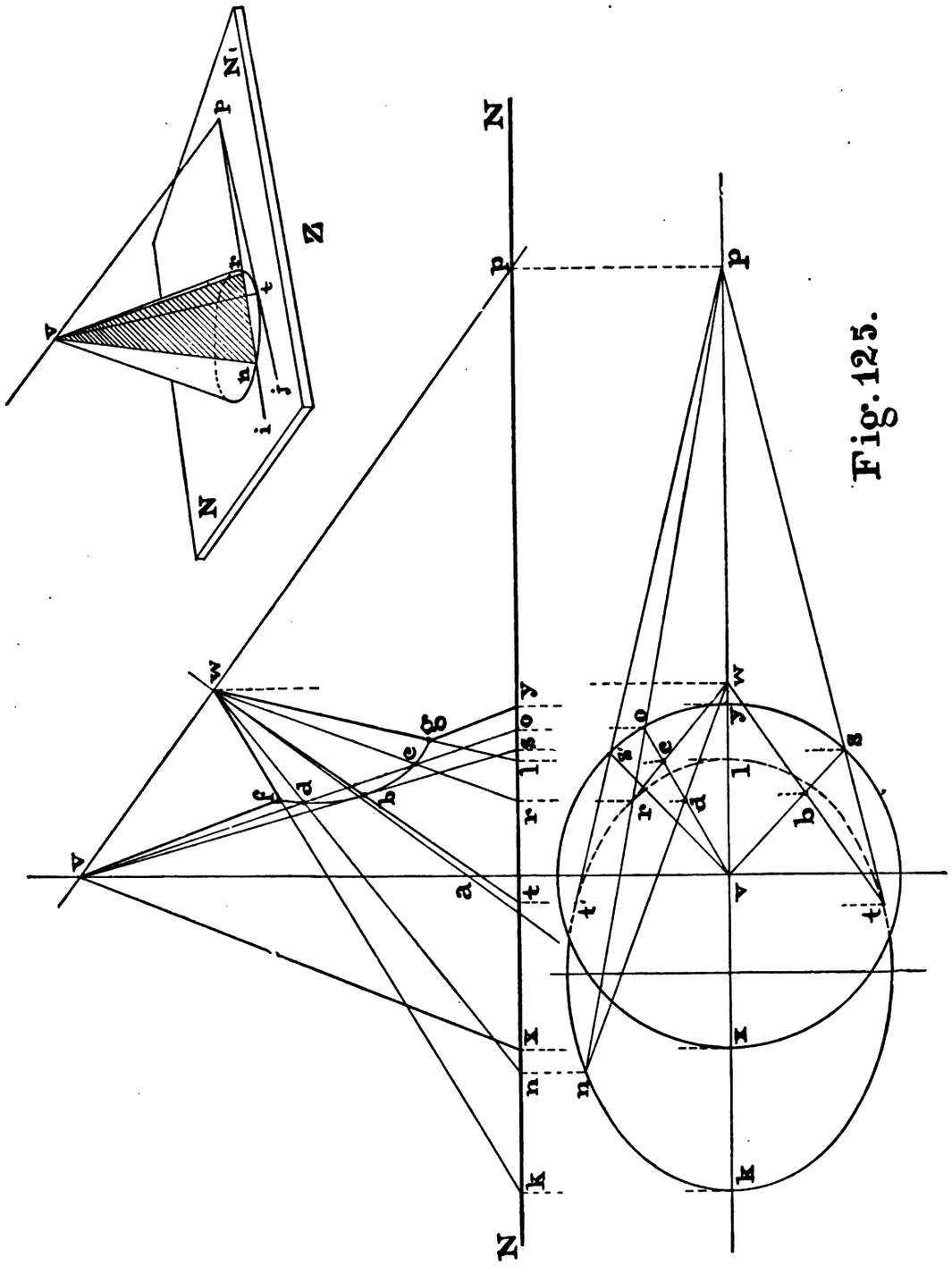


Fig. 125.

to avoid confusion, the curve is not drawn in the top view, the object being to exhibit as clearly as may be the mode by which the points are located.

The process of development, and the use of such limiting lines as *vs*, will be readily understood by referring to the explanation of Fig. 120; it being hardly necessary to add, that a right section of the inclined cone must be made at some convenient point upon its axis, which will develop into a circular arc.

200. Fig. 126 represents the hub of a screw-propeller, having the form of a sphere, with portions cut off by planes perpendicular to the axis at equal distances from the centre *o*: these planes also limit the edges of the blade, *ad* and *ce*. The surface of this blade (here supposed to have no sensible thickness) is the same as that of the square-threaded screw,

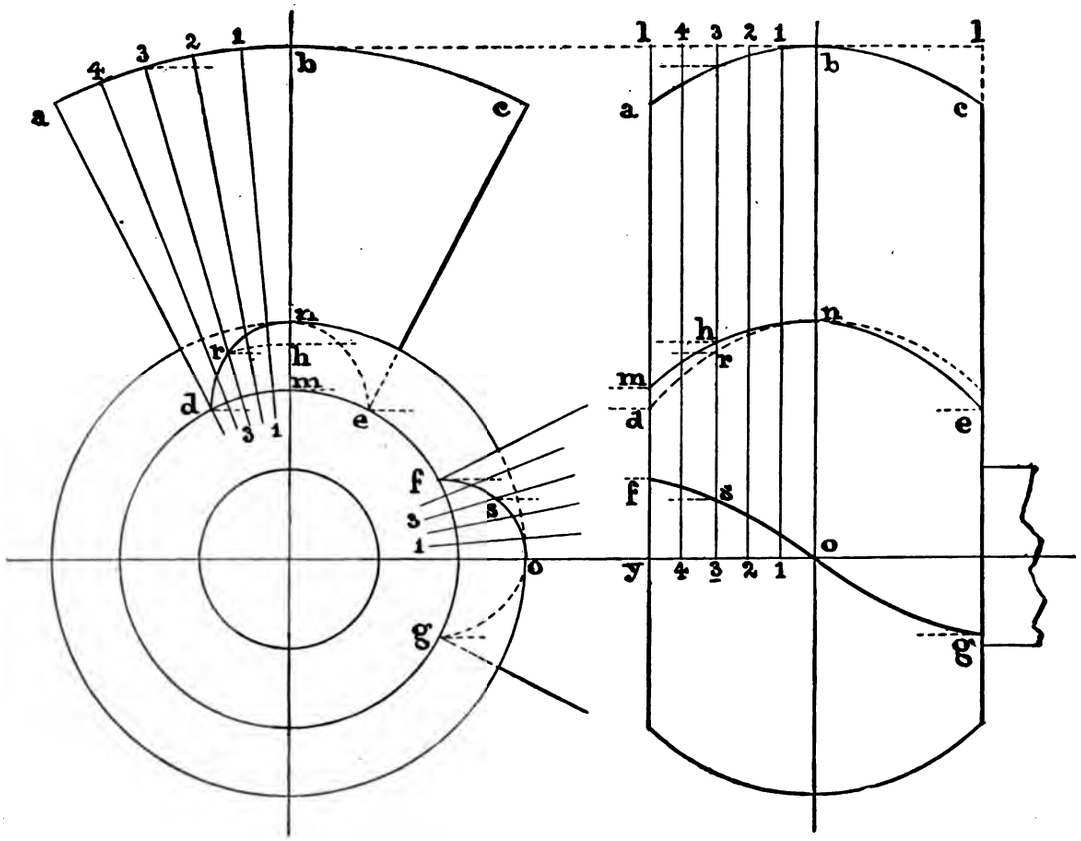


FIG. 126.

described in Chap. V: that is, it is generated by a straight line *bo* perpendicular to the axis, which, while travelling uniformly in the direction *oy*, also revolves uniformly about the axis as indicated by the radial lines in the end view, the point *b* describing the helical arc *ba*. It is now required to find the intersection of this surface with the hub.

If *bo* advanced along the axis without revolving, it would, when in the position $\underline{3}\ 3$, pierce the sphere at *h* in the front view; and $h\underline{3}$ is the actual distance from the axis at which it does pierce it. But it has meantime revolved to the radial position $3\ \underline{3}$ in the end view; therefore set off from the centre on this radius a distance equal to $h\underline{3}$, which locates the

point *r*: and in like manner any number of points on the intersection *drne* may be determined.

Which may be expressed by saying that a plane perpendicular to the axis cuts a right line from the blade and a circle from the hub, and the circle cuts the line in a point of the required curve.

If the hub be turned a quarter round toward the right, the curve *dne* appears in the position *fog*; this must be first drawn in the end view, with the radii as shown: the side view is then determined by projecting *f*, which is the new position of *d*, to *my*; *s*, the new position of *r*, to *h*$\underline{3}$; and so on.

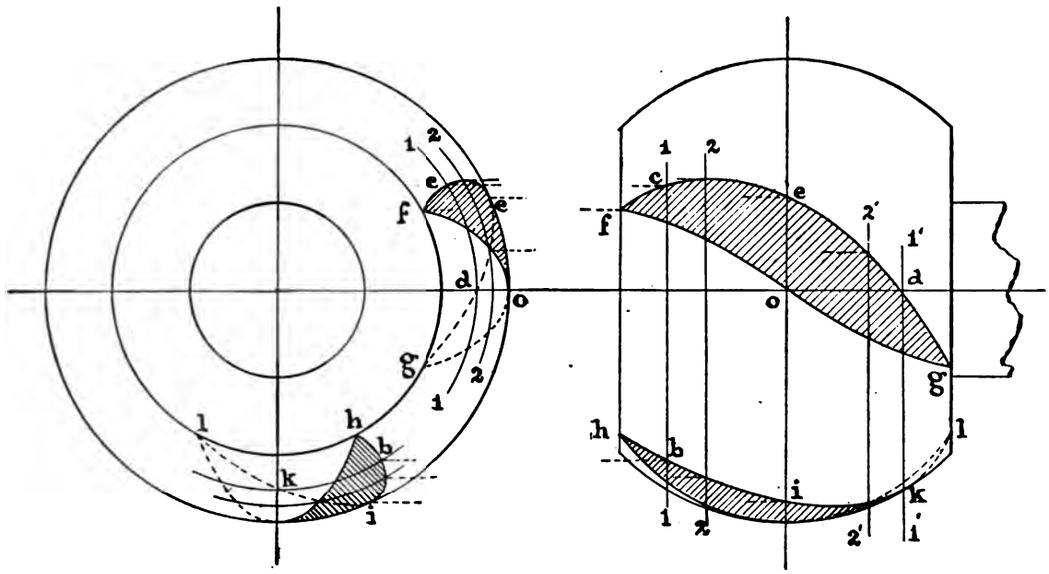


FIG. 127.

201. The blade of a propeller must have sensible thickness; and in forming the back, it is common to assume the curve of intersection with the hub, which determines the thickness of the blade at the root. In Fig. 127, the hub, and the intersection *fog* with the acting face, are the same as in Fig. 126; and *fceg* is the assumed line of junction of the back with the hub, in the front view. To construct the end view, make transverse sections 1 1, 2 2, etc.: these appear in the end view as circles, to which the points *c*, *e*, *d*, and so on, are projected from the front view.

Turning the hub to the right through an angle of 90°, the curve appears as *hbikl* in the end view, and the front view is constructed from this by projecting the various points back to the planes 1 1, 2 2, as in the preceding example.

It may be noted, that by making the sections equidistant from *o* in the front view, as for instance 1 1, 1′ 1′, each pair will be represented by one circle in the end view, which thus serves for the location of two points: thus *c* and *d* lie upon the circular arc 1 1, and so on. This expedient can be employed, of course, only when, as in the example here selected, the outline of the hub is symmetrical with respect to a transverse plane,—which is not by any means always the case in practice.

CHAPTER VII.

ISOMETRICAL DRAWING, CAVALIER PROJECTION, AND PSEUDO-PERSPECTIVE.

ISOMETRY.

202. In Fig. 128, *C* is a top view of a cube so placed that in the front view *A* the diagonals *cg*, *ab* of its upper face are respectively parallel and perpendicular to the paper. The cube is shown as cut by a plane *pp*, perpendicular to the paper in view *A*; the section thus made, as seen in the perspective sketch *V*, is bounded by the three face diagonals *ab*, *ad*, *bd*: it is, then, an equilateral triangle, to the plane of which the three equal edges *ca*, *cb*, *cd* are equally inclined. And as seen in view *A*, this plane is perpendicular to the body diagonal *ch* of the cube, which pierces it at *o*.

In the view *D*, which is an **orthographic** projection upon the plane *pp*, the three face diagonals are seen in their true lengths, forming the equilateral triangle *a'b'd'*. Since the three edges which meet at *c* are equally inclined to the plane, they will be equally foreshortened: therefore *c'* is the centre of the triangle, *a'c'*, *b'c'*, *d'c'* are equal to each other, and the three angles at *c'* are each equal to 120°.

Every other edge of the cube being equal and parallel to one of these three, each visible one will appear equal and parallel to one of those already drawn; thus the apparent contour of the entire cube will be a regular hexagon, the representation of each face being a rhombus.

Because the edges of the cube are thus foreshortened in the same proportion, so that they and all parallels to them may be measured by the same scale, such a view as *D* is called an **Isometric Projection**; *a'c'*, *b'c'*, *d'c'* are called the *isometric axes;* the planes which they determine, and all planes parallel to them, are called *isometric planes;* and all lines parallel to the axes are called *isometric lines.*

203. Drawings made in this manner possess the advantage of conveying, in one view, ideas of the three dimensions, as do those made in perspective; and in many cases they exhibit the peculiarities of structure more clearly than ordinary plans, sections, and elevations. They are readily understood by those who are not familiar with common projections; and in making sketches this system is very useful.

Obviously, however, the advantages of isometry are more pronounced when the objects to be represented are bounded by right lines, of which the principal ones are parallel and perpendicular to each other. It is not well adapted for the general drawing of machinery, since it involves an unpleasant distortion, and also because in most cases the circles are projected as ellipses.

204. *Distinction between isometrical* **projection** *and isometrical* **drawing.**—In Fig. 128 the actual length of the edge of the cube is *cd*; its apparent length in view *D* is *c'd'*, equal to *od* in view *A*. Suppose *cd* to be one unit in length—an inch for example: then by taking *od*

as a unit it is possible to construct an *isometric scale*, by which all the isometric lines in *D* might have been set off; and such a scale could be used in constructing any isometrical *projection*.

This is a matter of purely abstract, theoretical interest, and not of any practical use whatever. Since the isometric lines are all *equally* foreshortened, there is no reason why they should be represented as foreshortened at all. Consequently an **Isometric Drawing** of the given cube is made as shown at *E*, each edge being drawn of its true length. This is the method always adopted in practice, the scales in common use being alone employed. The man who should construct a true *projection*, and send it to the workman to be measured, by

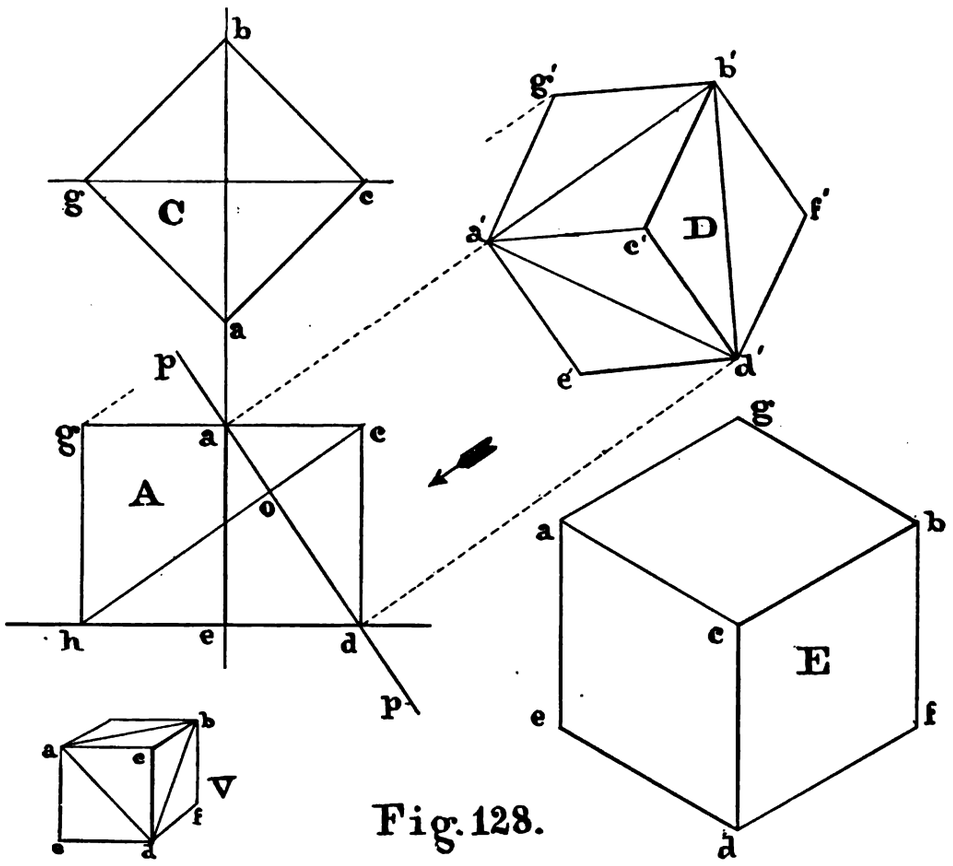


Fig. 128.

an isometric scale, would simply make a record of his own stupidity; he who should teach others to do so, would commit a blunder of much more serious importance. For, to use the words of another, "the value of isometry as a practical art lies in the applicability of common and known scales to the isometric lines."*

205. We proceed, then, just as in making ordinary working drawings, setting off the dimensions on those lines either "full size," or with the 3-inch scale, the 1½-inch scale, etc., as the case may require. Naturally, lines which are vertical are so represented; the other

* W. E. Worthen.

isometric lines are then drawn with great facility by the aid of the T-square and the triangle of 60° and 30°.

Figs. 129–134 are simple exercises, composed wholly of isometric lines, the construction being so obvious that no detailed explanation is required: the method of locating the foot of the cross in Fig. 132, and the mortise and the tenon in Fig. 134, by measuring along the lines *ca*, *cb*, or parallels to them, is sufficiently shown by the dotted lines.

It is to be distinctly understood that these figures are illustrations merely: the student is not to *copy* them, but to construct them or others of similar character, with such variations of dimensions, arrangement, or design as may be suggested by his ingenuity, which should be given full play.

In regard to the shadow-lines, reference is made to a cube as a standard. Thus in *E*, Fig. 128, the light is supposed to have the direction of the body diagonal *af*; consequently

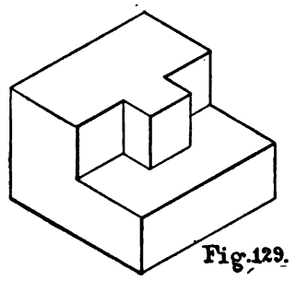


Fig. 129.

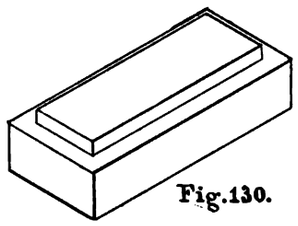


Fig. 130.

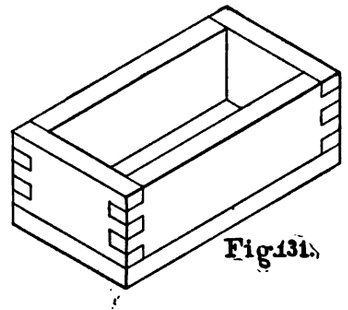


Fig. 131.

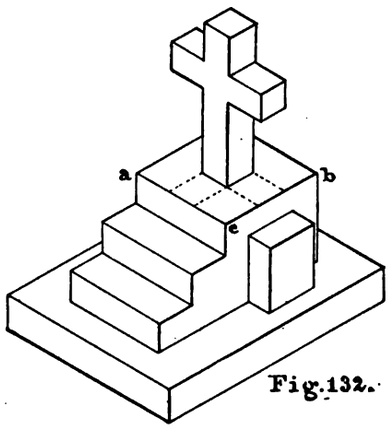


Fig. 132.

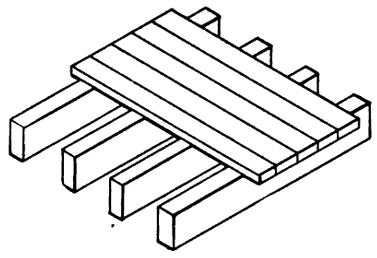


Fig. 133.

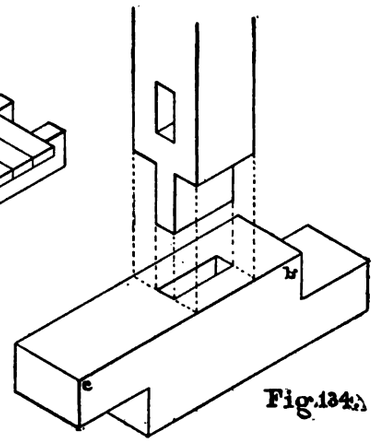


Fig. 134.

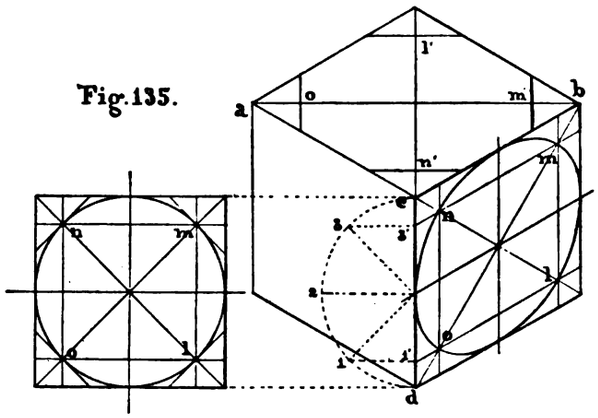
the faces *ec*, *cg* are illuminated, and shadows are cast by the edges *ed*, *dc*, *cb*, and *bg*. In drawing, the first of these lines should be made the heaviest, the last one the lightest, and the other two of equal and medium thickness.

206. Isometrical Drawing of the Circle.—The ellipse representing the circle inscribed in the face of the cube, Fig. 135, might be drawn by the method of Fig. 40 (Chap. II). But the axes coincide with the diagonals, and are at once determined by representing the parallels through *l*, *m*, *n*, *o*, in the elevation shown at the left. Describe a semicircle upon *cd* as a diameter, divide it into four equal parts by the points 1, 2, 3, draw 3 3′, 1 1′ perpendicular

to *cd*, and through 3′ and 1′ draw parallels to *bc*; these will cut the diagonals at *m*, *o*, and *n*, *l*, thus limiting the major and minor axes. As a check, note that *lm* and *on* should be parallel to *cd*.

The sides of the rhombus being equal, this construction may be made upon either one at pleasure. And, since all the faces of the cube are exactly alike, it follows that all circles lying in isometric planes are represented by similar ellipses.

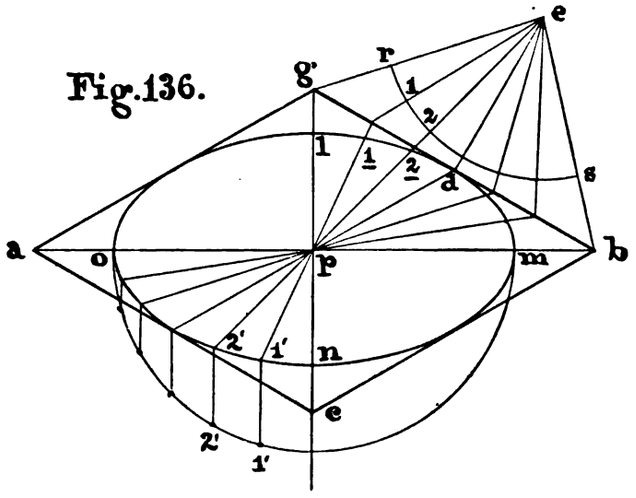
Fig. 135.



By drawing tangents at the points *l*, *m*, *n*, *o* in the elevation the circle is circumscribed by a regular octagon, the isometric representation of which is therefore made by drawing at the corresponding points *l′*, *m′*, *n′*, *o′*, in the upper face of the cube, perpendiculars to the diagonals, terminating in the sides of the rhombus.

207. Graduation of the Isometric Circle.—*First Method.* At the middle point *d* of *gb*, in Fig. 136, erect a perpendicular *de* equal to *db*, and draw *eb*, *eg*; about *e* as a centre

Fig. 136.



describe with any radius the quadrant *rs*, divide it as desired by the points 1, 2, 3, etc., through which draw radii and produce them to cut *gb*. From these intersections with *gb* draw lines to *p*, the centre of the ellipse: these will cut its circumference in the required points of division, $\underline{1}$, $\underline{2}$, etc.

Second Method. Describe a semicircle upon the major axis *mo* as a diameter, divide it in the desired manner by the points 1′, 2′, etc., through which draw perpendiculars to *mo*, cutting the circumference of the ellipse in 1″, 2″, etc.: these will be the points required.

An application of the above is shown in the drawing of the bolt, nut, and washer, Fig. 137. About *p*, the centre of the outer ellipse, describe an arc with radius *po* = semi-major

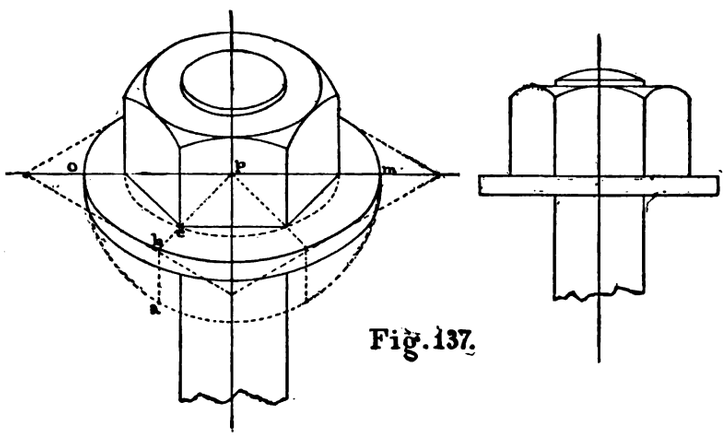


Fig. 137.

axis, set off the arc $oa = 60°$, erect the vertical *ab*, and draw *bp* cutting the inner ellipse (circumscribing the base of the nut) in *c*.

208. To draw Angles to the Sides of the Isometrical Cube. (Fig. 138.)—Draw a square *cg*, whose side is equal to the edge of the cube; about one of its angles, say *c*, as a centre, describe the quadrant *ab*, graduate it, and produce the radii through the points of division to cut the sides of the square. The scale of tangents thus formed may, by cutting out the square, be applied to any side of the isometrical cube, thus determining the direction

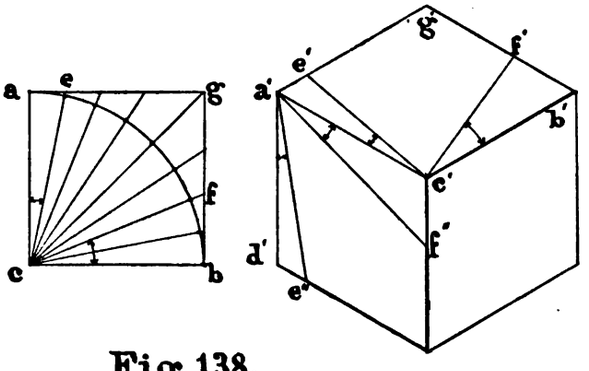


Fig. 138.

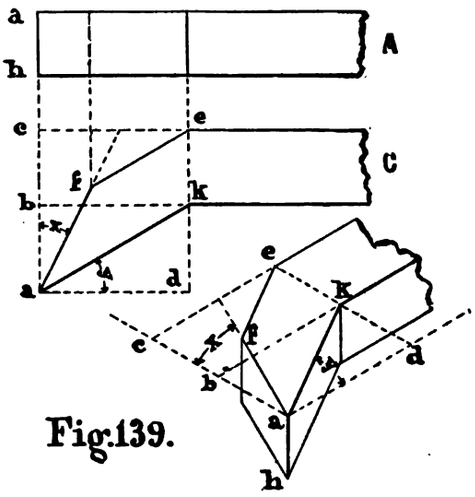


Fig. 139.

of a line in its face which shall represent a line making any required angle with its edge. For example, make $a'e' = ae$, and $b'f' = bf$: then $a'c'e'$, $b'c'f'$ are the isometrical representa-

tions of the angles *ace*, *bcf*. The same angles are represented on the left-hand vertical face of the cube by making $d'e'' = ae$, $c'f'' = bf$, and drawing $a'e''$, $a'f''$.

An application of this is found in making the isometrical drawing of the piece shown in plan and elevation at *C* and *A*, Fig. 139, in which the angles x, y are assigned: also in *C* the distance *ad* is given, *dke* is perpendicular to *ad*, and *ef* parallel to *ak*: the thickness is uniform, and equal to *ah* in view *A*. The isometric drawing is lettered to correspond, and should require no further explanation.

209. Another method of dealing with lines which, though lying in isometric planes, are not parallel to either of the isometric axes is by means of "offsets." Thus in Fig. 140 the slope of the diagonal brace is determined by measuring the distances *cd*, *de* along the isometric line *ca*, and setting up the vertical *ef*, of the values ascertained from the elevation

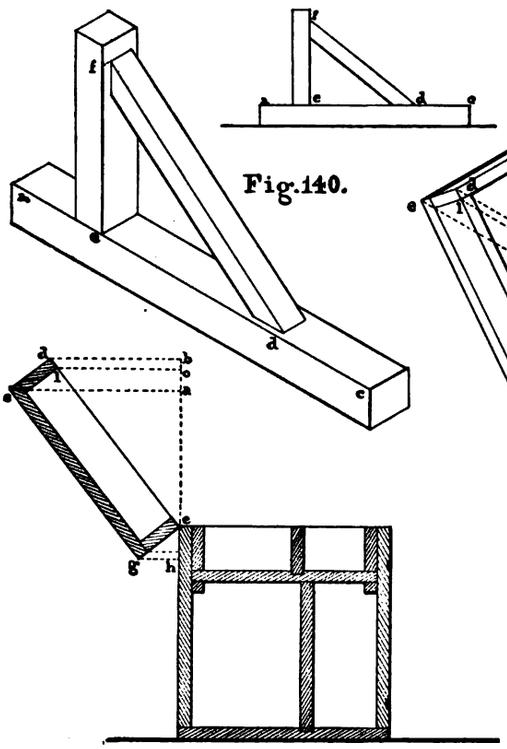


Fig. 140.

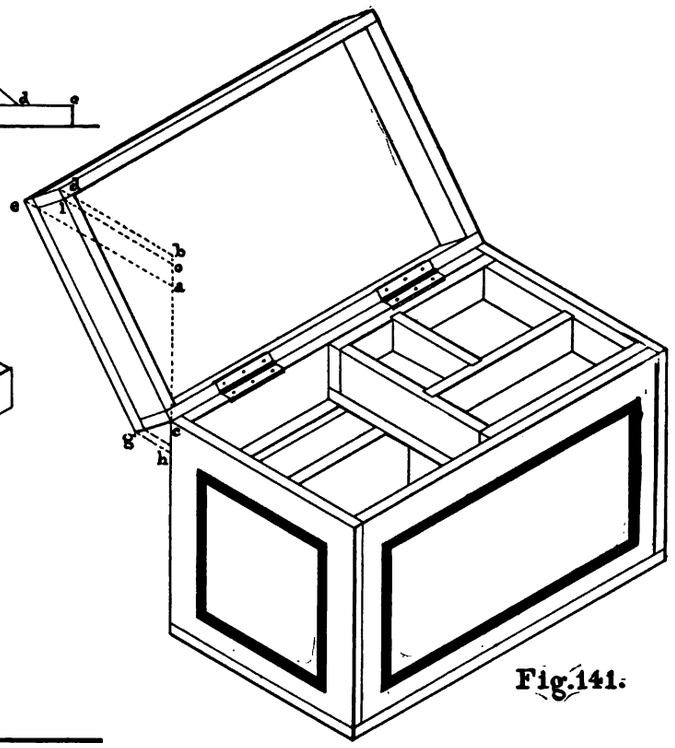


Fig. 141.

shown on a reduced scale. This really amounts to the same thing, the angle being constructed by laying off the base and altitude of a triangle of which the required line is the hypothenuse,—which is in perhaps the majority of cases the most convenient means. Another illustration is given in the drawing of the box, Fig. 141; the outline of the end of the partially opened lid being set out by means of the vertical measurements *ca*, *co*, *cb*, *ch*, and the offsets *ae*, *ol*, *bd*, *hg*, taken directly from the transverse section shown at the left.

210. This principle may be extended, and is applied to the determination of lines which do not lie in isometric planes; as illustrated in Fig. 142, representing the roof of a cottage, of the form and proportions shown in plan and elevations on a smaller scale at the right.

The sloping lines of the roof at the nearer end are found by setting up the heights *ab*, *ad* on the vertical through *a*, and drawing the isometric lines *bh*, *df*: then the points *i*, *k* are the intersections of *bf*, *fh* with the isometrical line through *c*. A similar construction may be made at the farther end, thus fixing the line of the ridge *ff'*, on which the point *g* is located by setting off *fg*, its distance from the plane *de*: we can then draw *gi*, *gk*, which do not lie in any isometric plane.

The same process is applied in drawing the wing roof, the heights *n*, *v*, *r* being set up on the vertical through the nearer corner *m*, and the distance *oq* measured from the plane *mo*. The ridge line will pierce the main roof at a point *u*, which may be thus located: Set up *at* = *mr*, draw the isometric line *ts* cutting *bf* in *s*, and through *s* draw a parallel to *ff'*: this will cut the ridge line of the wing in the required point.

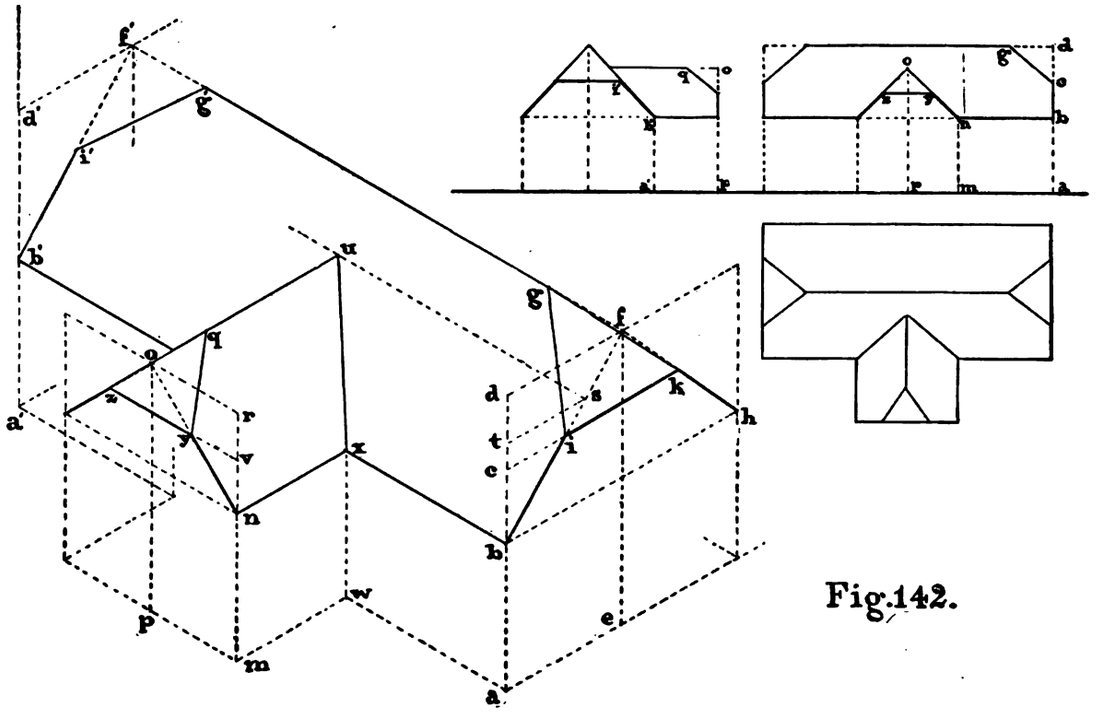


Fig. 142.

It will be observed that the lines *fh*, *gk*, and *ff'*, differ very little in direction, and *qz*, *ou* differ still less. This simply shows that the farther side of the main roof is very nearly, and that of the wing roof almost exactly, perpendicular to the plane upon which the isometric drawing is made; and it will be perceived that in such cases this is not a peculiarly eligible mode of representation,—as indeed it is not for architectural subjects of any description.

211. Thus far one of the isometric axes has been made vertical. But inasmuch as it is the relative direction of the lines among themselves which determines whether a drawing is an isometric one or not, there is no necessity that any of them should be vertical. In Fig. 143, for example, the principal lines are horizontal; but the drawings of the die and its

matrix, and of the timber with its mortises and its tenon, are at once recognized as isometric, and are just as easily understood as if they stood upright.

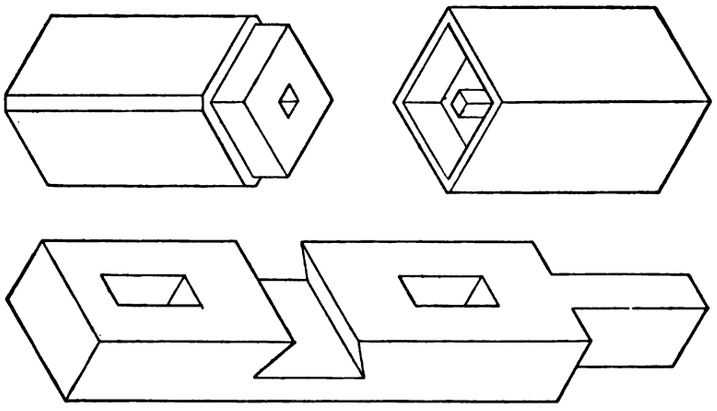
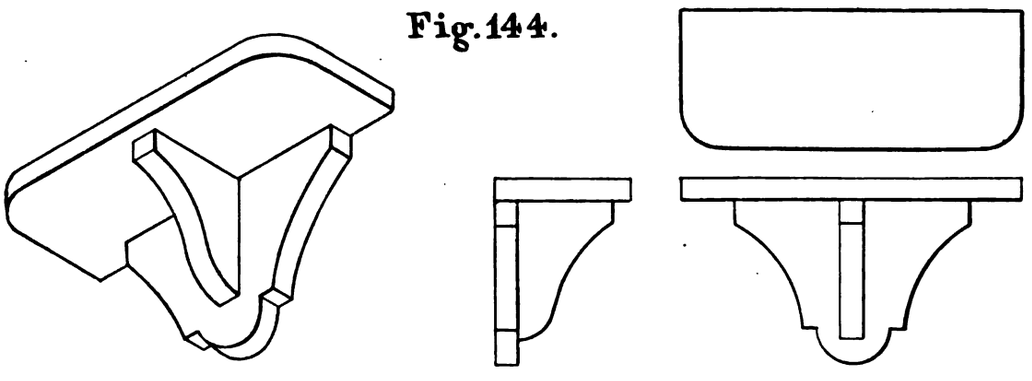


FIG. 143.

For convenience in constructing the drawings by means of the T-square and triangles, it is preferable in most cases, of course, that one of the isometric axes should be either vertical or horizontal, but should there be any reason for selecting other positions, there is nothing in the principle of isometry to prevent their adoption.

Fig. 144.



212. It will be noted that the correspondence of the die to the matrix in Fig. 143 is made much more obvious than it otherwise would be, by exhibiting the opposite ends of the two pieces. By merely turning the page around, it will be apparent that this could have been done equally well if the two pieces had been drawn in a vertical position.

For this reason isometry affords a means of illustrating in a very clear and striking manner many subjects in which views of the lower surfaces are desirable: a good example is shown in the drawing of the small shelf with its supporting bracket, Fig. 144.

In making such a drawing, as will readily be seen, the process is equivalent to constructing the projection of the cube, Fig. 128, upon the plane *pp*, as seen from the lower left-hand side, and looking in the direction opposite to that indicated by the arrow.

213. In Fig. 145 is shown an isometric drawing of the ratchet-wheel represented in the full size views at the right. The backs of the teeth not only terminate in, but are tangent to, the interior circle; and a test of the accuracy of the isometric drawing is found in the tangency of the edges to the ellipse representing that circle. And this embodies a principle capable of many other applications—as, for instance, in laying out a wheel with radial tapering arms: the side outlines of each arm are tangent to a circle, which being drawn in the isometric construction, it is seen that the breadths of the arms at the outer ends only need be set out, thus fixing points through which tangents are to be drawn to the ellipse.

214. It seems needless to multiply examples, as it is believed that by the aid of the preceding any isometrical drawing likely to be required in practice may be constructed.

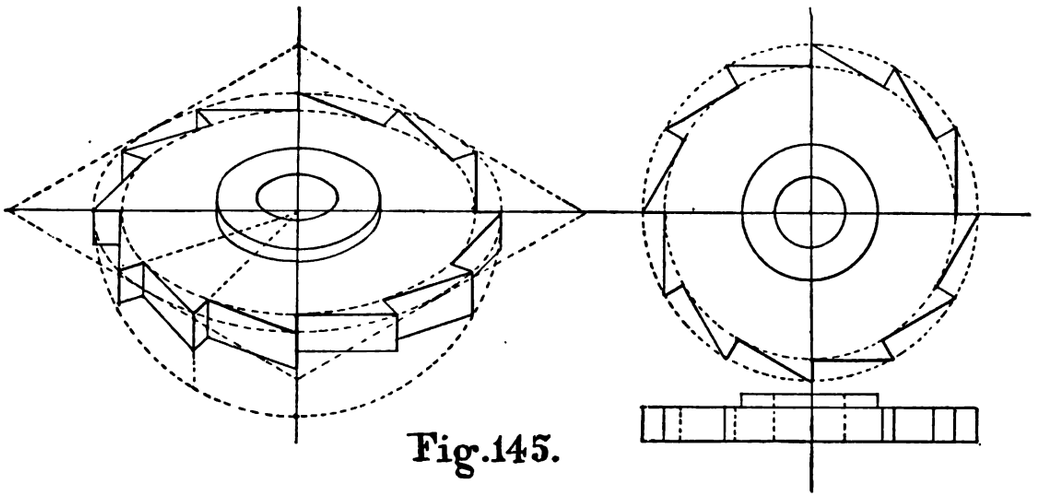


Fig. 145.

In drawings of machinery, the circles of wheels, bearings, ends of shafts, and the like, will usually lie in isometric planes. Should occasion arise to represent one which does not, circumscribe it by a square: the projection of this will be a parallelogram, within which the ellipse may be drawn by methods previously explained. So, too, if it should be necessary to represent the section of a cylinder or a cone by an oblique plane, the solid may be conceived as surrounded by a square pyramid or prism, whose section by the given plane, as well as the isometric drawing of it, will be a parallelogram circumscribing the required ellipse.

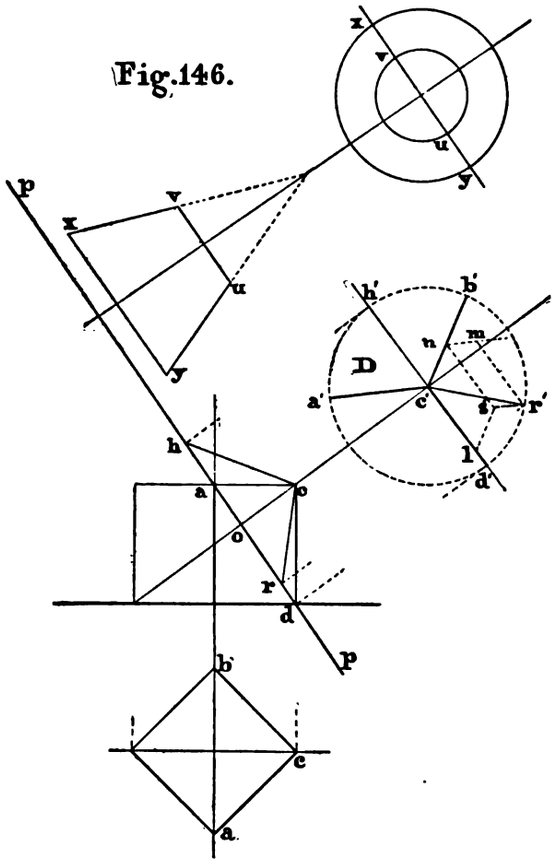
215. In conclusion, it may be pointed out that many lines not usually classed as *isometric* are strictly so in fact. This distinctive term is technically restricted to lines parallel to the isometric axes, which again are so called because they are equally foreshortened, and this is the result of their equal inclination to the plane upon which they are projected. Now, in Fig. 146 the cube is cut by the plane *pp* as in Fig. 128, and in the projection *D* we at once recognize $c'a'$, $c'b'$, $c'd'$ as the isometric axes. If *cd* revolve around *co* as an axis it will generate a cone *dch*, all of whose elements make the same angle with the plane *pp*; so that any one of them, as *cr* (seen in *D* as $c'r'$), would be foreshortened in the same proportion as any other one. But in the isometric projection this fact would not be indicated by merely drawing $c'r'$: it is necessary to locate the point r' by means of offsets—$c'n$ giving its distance from the plane $a'c'd'$, $c'l$ its distance from the plane $a'c'b'$, and *nm* its distance from the plane $b'c'd'$.

This being done, s' is at once seen to be the foot of the perpendicular $r's'$ from the point in question to the plane last mentioned.

Again, the isometric projection of any frustum of a cone, *xyuv*, whose bases are parallel to *pp*, would appear simply as two concentric circles, and without some auxiliary view that projection would convey no definite information about the cone, which might be of any altitude or have either base uppermost.

Since the whole value of isometry, in practice, lies in the power of imparting in one view

Fig. 146.



definite ideas of the three dimensions, the above hints may serve a purpose as indicating possible relations of parts for the representation of which this method of drawing is not suitable.

CAVALIER PROJECTION.

216. In Fig. 147, let *MN* represent a vertical glass plate (corresponding to one side of the show-case, Fig. 68); let *c* be a point in this plane, and *ca* a line perpendicular to it. Let *ar* be a visual ray, making an angle of 45° with the plane *MN*, and piercing it at *p*: then *cp* is the representation of *ca* upon the picture plane, and it is equal to *ca*, because the angles *cpa*, *cap* are each equal to 45°.

Suppose the eye to be at an infinite distance in the direction *ar*: then all the visual rays

will be parallel, and all lines perpendicular to *MN* will be represented upon that plane by lines of their actual length, and parallel to *cp*.

The fact that the projection is of the same length as the perpendicular line depends upon the condition that the picture plane cuts the projecting lines at an angle of 45°. But the direction of the projection depends upon that of the visual ray. Thus if the eye be still at

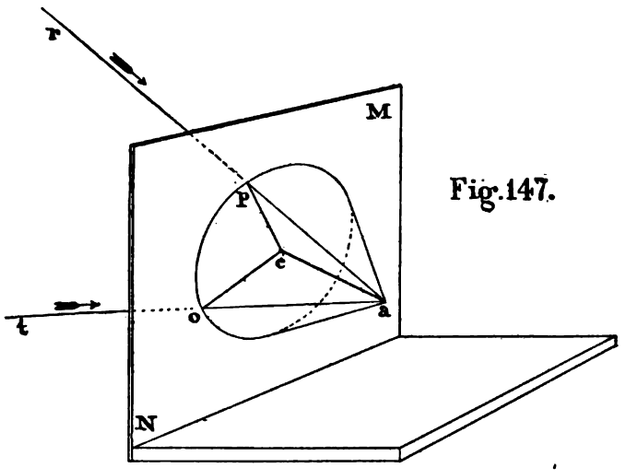


Fig. 147.

an infinite distance, but in the direction *at*, the projection will have the direction *co*, but its length will remain equal to *ca*.

Thus the direction of the projecting lines may be parallel to any element of the cone whose axis is *ca*, the angle at the vertex *a* being 90°, since all these elements make angles of 45° with the picture plane *MN*.

217. Now any line which lies in the picture plane is its own projection. In representing a cube, therefore, as in Fig. 148, we may assume its nearer face to lie in that plane, and it will thus appear of its true form and size, that is, a square, as shown. From the preceding it follows at once that the edges which are perpendicular to *MN* may be represented by parallel

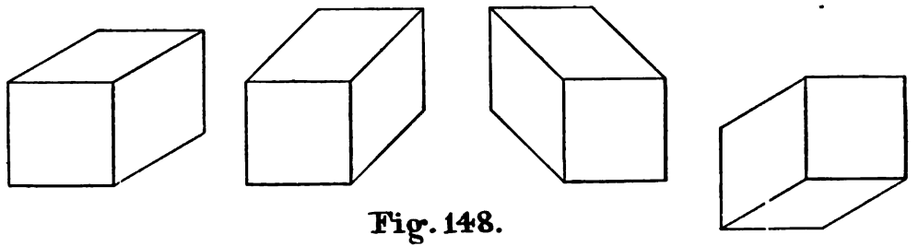


Fig. 148.

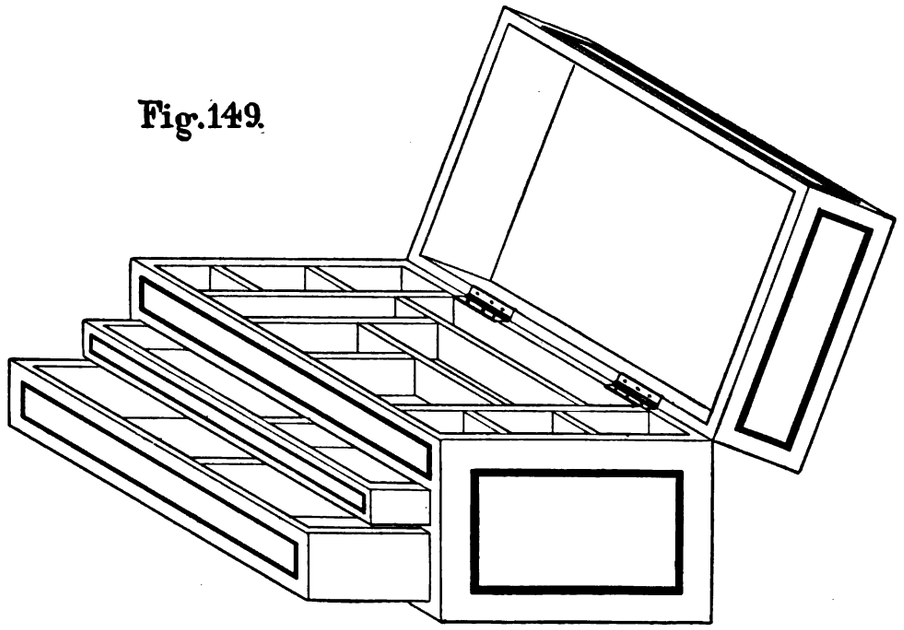
lines of their true length, but having any direction at pleasure; which enables us to show, in addition to the front face, either the right face or the left, the upper or the lower, as may best suit our purpose. And, as the figure shows, either of these faces at will may be made more conspicuous than the other by proper selection of the angles.

We have, then, a system of true *oblique projection:* it is more flexible than the isometric,

always quite as easily executed and in many cases more so, and like it exhibits the three dimensions in one view. All lines lying in planes parallel to the paper are shown in their true forms and relations; and not only these but lines perpendicular to the paper are shown of their actual dimensions, the introduction of any such senseless appliance as the "isometric scale" being prevented by the very nature of the process.

218. This system is well adapted for purposes similar to those in which isometric drawing

Fig. 149.



is employed,—such as the representation of joiner-work, as exemplified in the case of the box, Fig. 149, and in that of the peculiarly notched and fitted pieces shown in Fig. 150. In the

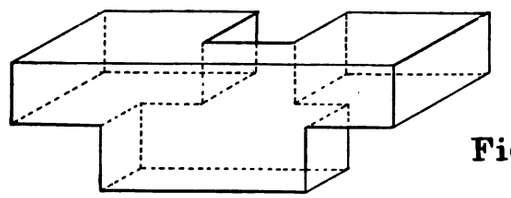
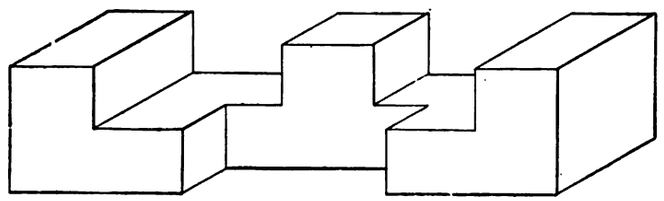


Fig. 150.



illustration, and especially in the sketching of small mechanical details, it possesses the decided advantage over isometry that, as shown in Fig. 151, circles whose planes are parallel to the paper are represented by circles, which greatly expedites the work of construction.

Those lying in planes perpendicular to the paper, however, must here too be represented by ellipses: since each circumscribing square is projected as a rhombus, the axes will coincide with the diagonals, and may be found as in Fig. 135.

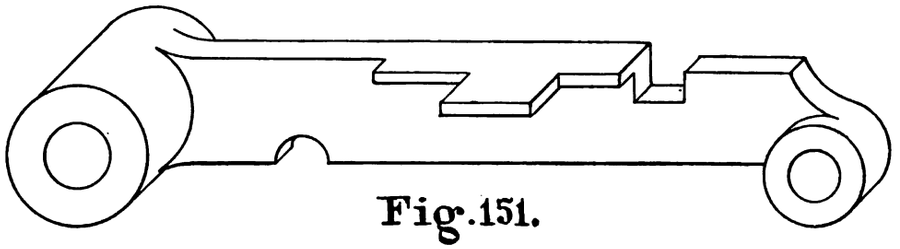


Fig. 151.

The use of ordinates, or offsets, in determining lines which are neither parallel nor perpendicular to the paper is substantially the same as in isometric drawing. Thus in Fig. 152

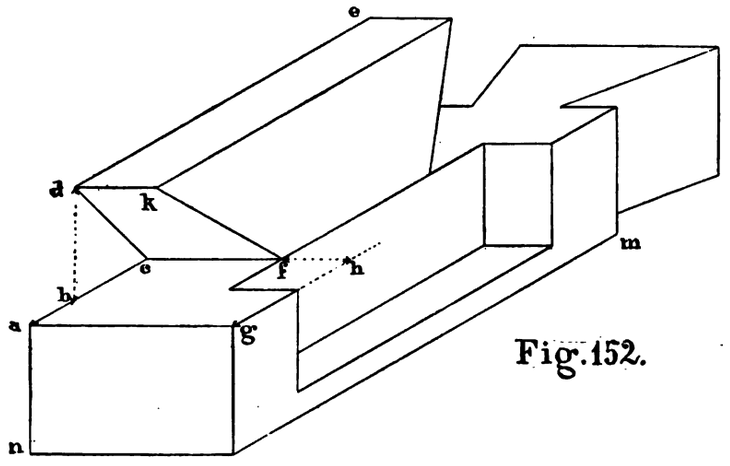


Fig. 152.

the point *f* in the plane *cg* is located by setting off *gk*, its distance from the plane *gn*, and then *hf*, its distance from the front plane *gm*; the point *k* is determined by *ab*, its distance from the end plane *gn*, *bd* its height above the plane *cg*, and *dk* its distance in front of the rear plane, which is invisible. The two points *f* and *k* being thus fixed, the projection of the line *fk* is determined; and the rest of the construction can be readily traced without explanation.

The lines which cast shadows, and are therefore to be made heavy, can usually be determined by inspection,—the light, as in the common orthographic projections, being supposed to come from over the left shoulder, and to go downward to the right as it recedes, in the direction of the body diagonal of a cubical room upon the wall of which the paper is hung, in front of the observer.

219. There is, then, no need to pursue this subject farther: the principles which have been thus briefly set forth are sufficient for applying either of these modes of projection to any subjects within the common range of practice. Both are very useful, with certain limitations which have been suggested, and the question whether either is suitable for any given case can be settled by experience alone.

But one thing has been decided by experience beyond all question; and that is, that the attempt to apply either isometric or cavalier drawing in the construction of a general plan of any complex machine is certain to result in a melancholy failure: the distortion, less noticeable in the case of minor details and detached pieces, becomes unendurable when the various parts are assembled.

PSEUDO-PERSPECTIVE.

220. For the purpose of producing a certain effect of relief, and conveying at least some idea of the three dimensions, while at the same time avoiding this distortion as well as the labor of constructing a true perspective drawing, a mode of representation has been devised,—to which the name of Pseudo-Perspective seems appropriate,—of which we give a single illustration in Fig. 153.

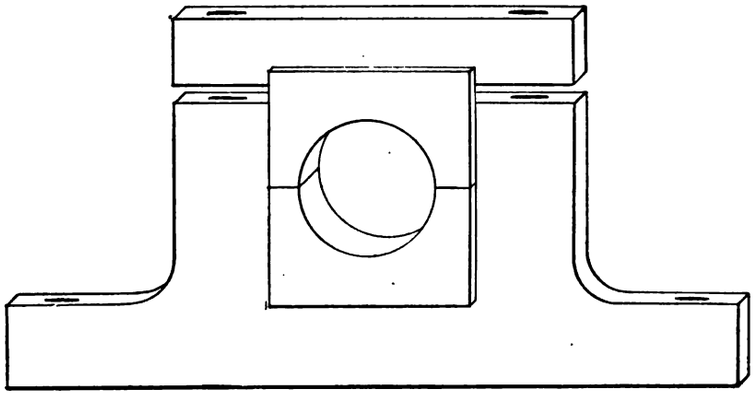


FIG. 153.

This is, in principle, a modification of cavalier projection; in that, as has been stated, the parallel projecting lines are inclined to the picture plane at an angle of 45°. But, referring to Fig. 147, it will be seen that if the cone of visual rays should have a less angle at the vertex, the projection of *ca* would be shorter; and by properly choosing this angle, the projection may be made shorter than the line in any desired ratio, while its direction is still entirely arbitrary.

The pseudo-perspective drawing, then, is made by representing the lines which are parallel to the paper in their true size, while those which are perpendicular to it are reduced to, say, one twelfth of the actual length, but parallel. This of course renders the result valueless as a working drawing; but it gives a sense of depth, and such representations are in many cases well suited for illustrations upon a small scale, such as cuts for encyclopædias and the like.

The distortion in the true cavalier projection is due to the mental recognition of the facts that the true representations of receding lines ought to converge, and that equal distances upon them ought to appear less as they recede. Both these errors are made less conspicuous by reducing the lengths of these representations, which is accomplished by the method of drawing above explained.

CHAPTER VIII.

THE SPUR-WHEEL AND THE BEVEL-WHEEL IN INCLINED POSITIONS. CONSTRUCTION OF THE CLOSE-FITTING WORM AND WHEEL. CONSTRUCTION OF THE SCREW-PROPELLER. STANDARD SECTIONING, ETC.

221. It is assumed that the student has now gained a knowledge of principles and modes of representation, and a degree of skill in the use of instruments, which will enable him to make presentable and accurate working drawings of mechanical details. But it is not proposed to give, as might be done, a collection of such drawings to be repeated as mere exercises.

Familiarity with the construction, and positive apprehension of the proportions, of any machine is best gained by actual examination of it; the copying of plans will never give an adequate idea of how the pieces would look when finished in accordance with them. The novice in designing is often much astonished when he sees in the solid the first piece for which he has made the drawing: he recognizes the form, of course, but it looks too large or too small, this part seems too light or that too heavy; and on the whole the physical appearance is somehow different from his mental conception of it. The fact is, let him who thinks he can, account for it as best he may, that there is a mysterious something in the relation between the drawing and the structure, the power to grasp which at once is born in few; and those who have it not by nature, will acquire it but slowly and painfully if they confine themselves to paper.

222. The intention therefore is, that the student should at once begin to acquire it in a more logical and practical manner. Instead of copying a plan, let him make measurements and sketches of some simple machine or part of a machine already built, and lay out a working drawing from the data thus obtained. Being thus obliged to take special note of the shape, size, and weight of the object in question, the impression upon his mind will be more distinct and lasting, and his drawing when done will convey to him a fuller meaning, than if the opposite course had been adopted; and besides, practice is had in a most essential acquirement.

The first efforts in this direction should be confined to comparatively simple subjects, of such dimensions that the drawings can be made **of full size**: the immediate object of this training is not to acquire skill in the construction of complex and difficult drawings, but to gain the power of forming, by inspection of any working plan, a correct conception of what it means. And experience has amply proved that this is best done by dealing at first with drawings of the same size as the objects themselves: whatever the reason may be, some little practice is usually needed in order to realize correctly in the mental image, the dimensions indicated by plans upon a reduced scale. Nature never acts *per saltum*, and this practice should progress by easy gradations.

223. Those who are left to instruct themselves must perforce devise for themselves the ways and means of making the measurements required; and if they succeed unaided, so much

the better for them,—just as it is better for a child thrown into the water to swim than to drown. But the best swimming-masters have decided that it does not pay to pitch applicants overboard and select classes from the survivors. Exactly so here: it is not the sole duty of an instructor, if there be one, to say "Sketch this," "Draw that," and then expect of his pupil a perfect result. If he knows how to show him how, it devolves upon him to do so if appealed to; and if the services of a thoroughly competent and experienced teacher are of value at any stage of progress, this is emphatically the one at which their value would be the greatest. And this not in regard to the sketching alone, but in the way of suggesting the best selection, and most important of all, the best arrangement, of the views which should be made in the working drawing.

In the second part of this work the matter of sketching is treated more at length, and hints in regard to arrangement will also be found in connection with the illustrations of that and other subjects.

We proceed, then, to the consideration of a few rather miscellaneous topics which may subsequently be found of service.

224. Drawing of a Spur-wheel in an Inclined Position.—In Fig. 154 we have an end view, a top view, and a section of a spur-wheel. Referring to Fig. 55 in relation to the forms of the teeth, it is sufficient to say that if the interior describing circle be of half the diameter of the pitch-circle the flanks will be radial lines, as here shown: the manner of drawing the top view and the section in this figure should require no explanation. Fig. 155 is a view of the same wheel, not in the direction of the axis as in Fig. 154, but at an angle with it. It is at once perceived that the pitch-circle *WW* will be projected here as an ellipse; and the points such as *c*, *d*, at which the teeth cut the pitch-circle, are projected to *c'*, *d'* in the top view in Fig. 154, and thence to *c''*, *d''*, upon the ellipse *W''W''* in Fig. 155.

Similarly, the tops of the teeth lie upon the outer circle of the wheel-blank, which also is seen as an ellipse in the inclined view; and so *a*, *b* are projected first to *a'*, *b'*, in Fig. 154, and thence to *a''*, *b''* upon the corresponding outer ellipse.

If any circles be drawn between the pitch-circle and the outside one, they also will be seen as ellipses in Fig. 155, and by treating as above the points in which they cut the outlines of the teeth, as many intermediate points may be determined.

A like proceeding would enable us to draw the contours of the flanks were they curved as in Fig. 55. For the sake of convenience they are here made radial; for which reason they will in Fig. 155 appear as right lines converging to the centre of the ellipse *W''W''*.

All of the above relates to the appearance of the nearer side, or rather end, of the wheel. In regard to the farther one, it is clear that a pitch-circle scribed upon it would also be seen in Fig. 155 as an ellipse similar to *W''W''*, of which a portion is shown at *Y''Y''*; and to this all the preceding applies in a way too obvious to call for explanation. The consequence is that the visible edges of the teeth, such as those through *a''* and *b''*, and the visible tangent elements, such as that through *x*, will be straight lines, of equal length, and of course parallel to the axis.

225. Drawing of a Bevel-wheel.—The basis of the bevel-wheel is a cone, *vab*, in the top view, Fig. 156. In the end view the base *ab* appears as a circle, which is called the *pitch-circle* of the wheel. The first step is to divide this circle into as many equal parts as the

wheel is to have teeth: this determines the *pitch*, measured by the arc *gi*, and the thickness *gf* is a little less than half the pitch.

Now draw at *a* and *b* lines perpendicular to *av* and *bv*; these meet the axis at *n*, and form the outline of a cone *nab*, normal to the pitch-cone. If this normal cone be developed, its base will become a portion of the circle whose centre is *n* and radius *nb*; an arc of which, *bgf*, is shown in the top view. Draw a radius of this arc at any point as *o*, on each side of which set off an arc, *of*, *og*, equal to half the arc *gf* in the end view. (Practically, it suffices to

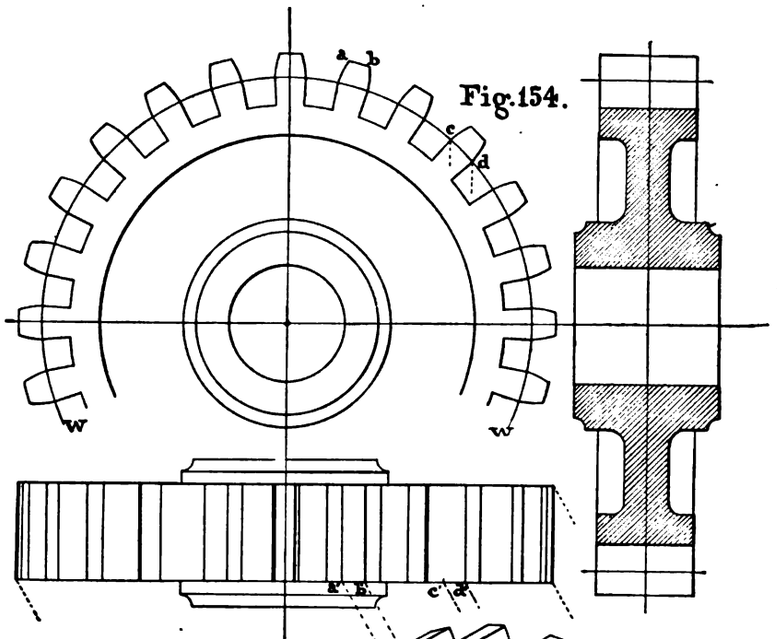


Fig.154.

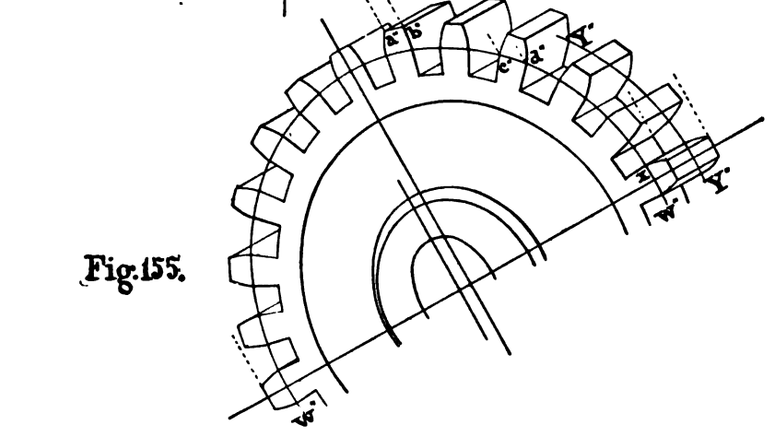


Fig.155.

bisect *gf* and set off that distance on each side of *o*, because, unless the tooth is of unusual thickness, the difference between the arc and its chord is inappreciable.) Construct and proportion the outline of a tooth, regarding *bgf* as an arc of the pitch-circle of a spur-wheel. If this developed tooth were cut out of thin metal, and wrapped back upon the normal cone, its contour would be that required for the tooth of the proposed bevel-wheel. The doing of

this graphically, it will be seen, is an application of the process explained in connection with Fig. 105.

226. Having determined the height *rs* of the tooth, make *br*, *bs*, in the top view and in the section, respectively equal to *or*, *os*: then the tops and the bottoms of the teeth will be limited by the circles described by *s* and *r* in revolving around the axis.

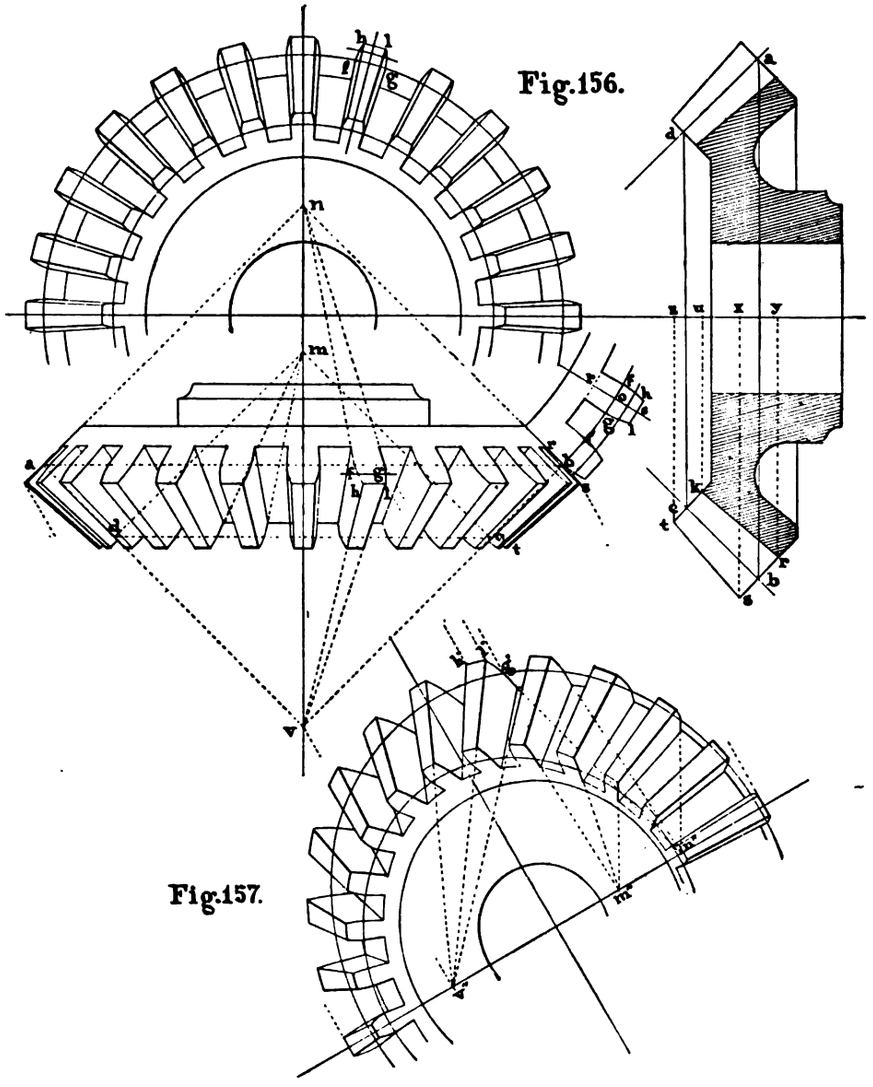


Fig.156.

Fig.157.

Next decide upon the length *bc* of the tooth in the sectional view, and draw at *c* a perpendicular to *bc*, also *rk*, *st*, converging to the vertex of the pitch-cone. It will be seen that the inner ends of the teeth lie upon another normal cone, *cdm*, in the top view, and that they will be of the same form as the outer ends, but smaller in the proportion of *tk* to *sr*.

The radius of the circle described by *s* is *sx*; upon this circle in the end view make *lh* equal to *lh* in the development: then the foreshortened view of the face curves will be *fh*, *gl*;

intermediate points in these curves may be found by means of intermediate circles, as indicated. The same method might be adopted for drawing the flanks, if they were curved; but since they are in this case made radial in the development, they will appear radial in the end view, and the apparent depth of the spaces between the teeth is limited by the circle whose radius is *ry* in the section.

The tops of the inner ends of the teeth lie upon the circle whose radius is *tz*, and their breadths may be determined by drawing radial lines as through *l* and *h*, the points limiting the breadth at the outer end; and these lines represent the edges of the teeth. So, too, radial lines through *f* and *g* cutting the inner pitch-circle whose diameter is *cd*, locate the junctions of the faces and flanks; since the latter in this instance are straight, they are also radial, and terminate in the circle whose radius is *ku* in the section.

227. One tooth having been laid out, all the others are copied from it in their proper positions in the end view. This is a necessary preliminary to the construction of the top view. In this, all the circles mentioned appear as straight lines, to which the points in which the tooth outlines cut these circles are projected from the end view, as shown at *f* and *g* on *ab*, *h* and *l* on the outer circle through *s*. Since the teeth are here made with radial flanks, the outlines of these will be straight, those upon the outer normal cone converging to its vertex *n*, and those which are visible at the inner ends of the teeth converging to *m*, the vertex of the inner normal cone.

It is thus quite evident that the correct drawing of the bevel-wheel is, if not a complicated, nevertheless quite a tedious, operation. Fortunately, this labor is not necessary for the purpose of simply having the wheel made: the shop drawing (Fig. 17, Part II) is far more easily made. But in a general plan of a complete machine, or for illustrative purposes, it may be necessary to draw such exterior views.

228. Drawing of a Bevel-wheel in an Inclined Position.—This involves no small amount of additional work, as will readily be seen by study of Fig. 157. But few words of explanation, however, are necessary, since the mode of operation is substantially the same as in Fig. 155. All the circles are now projected as ellipses, to which the various points of the tooth-outlines, as *g''*, *h''*, *l''*, are projected from the top view of Fig. 156. The vertices of the three cones appear in this new view as *v''*, *m''*, *n''* upon the axis, and to these points the edges of the teeth, the flanks at the inner and those at the outer end, respectively converge.

229. Drawing of a Worm and Wheel.—The form of this device selected for illustration is that commonly called the close-fitting tangent screw: a steel screw of the same size as that finally to be used is notched to make a cutter, which is then hardened, tempered, and used for cutting the teeth of the worm-wheel. In this operation the cutter can remove only just so much metal as to permit of rotation: the ultimate fit of the driving worm is therefore as perfect as it can be made.

In Fig. 158 the diagram on the left is a section through the axis of the worm and perpendicular to that of the wheel; that is to say, by a plane *LL* in the diagram on the right, which is a section of the wheel by a plane passing through its own axis, and perpendicular to that of the screw.

Let *C* be the centre of the wheel and *WPr* a portion of its pitch-circle, to which draw *TP* tangent at *P*; and regarding this as the pitch-line, the next step is to lay out teeth as for

this new involute will differ from the first one, within the limits used, so slightly that the difference will be inappreciable unless the work is on a prodigious scale. Practically, then, we may make this curve *bd* a portion of the same involute as the tooth-outline *aec*: we have now to determine its location and its limits.

233. The worm is a rack which advances by rotation; and one turn of it is equivalent to

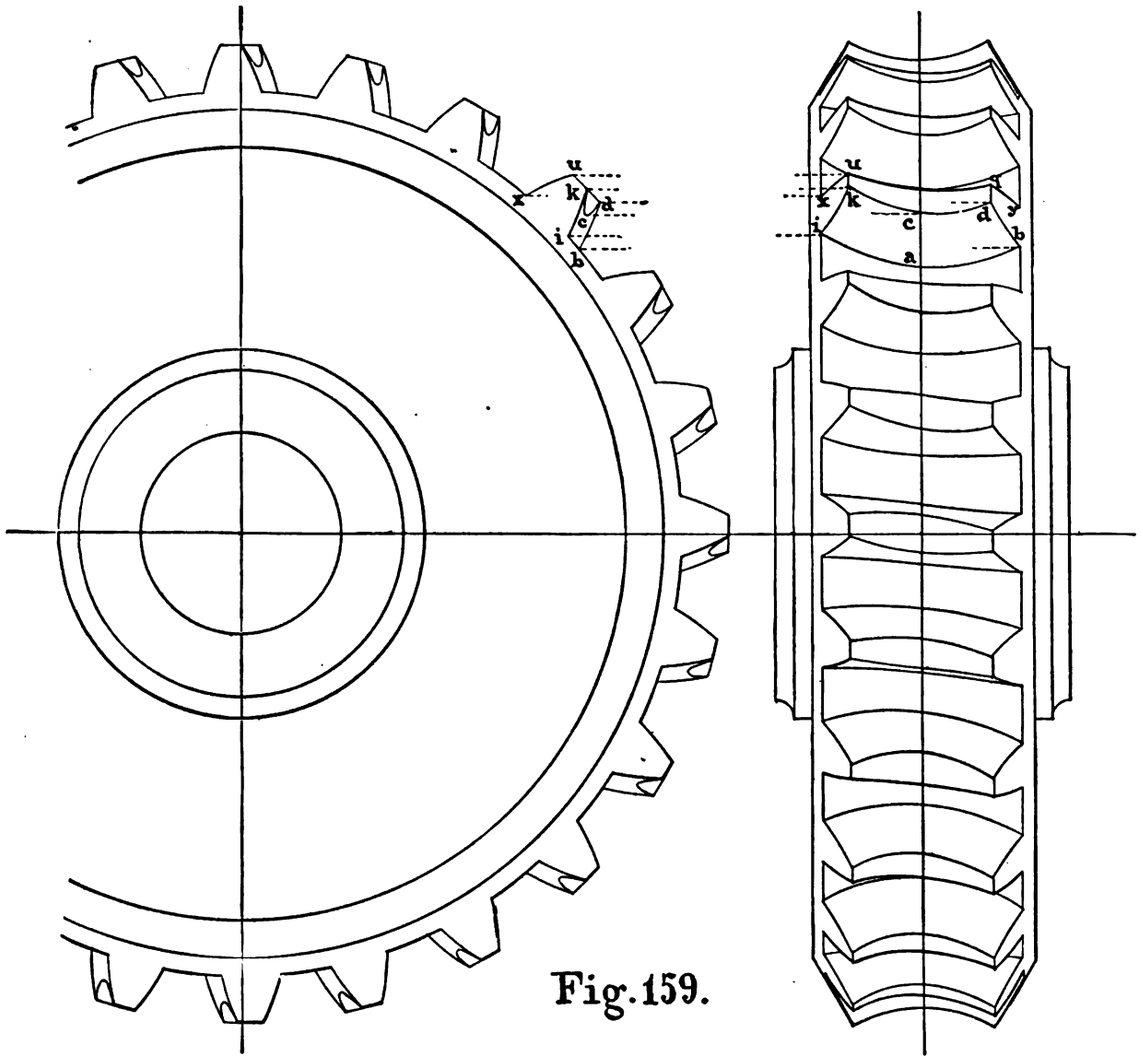


Fig. 159.

a longitudinal travel through a distance equal to the pitch. Now the angle *aOb* includes $\frac{1}{12}$ of the circumference; and in turning through this angle the worm would drive the wheel through $\frac{1}{12}$ of the pitch-arc. This fraction of the pitch, then, is set off from *e* on the pitch-circle *WPr*, thus locating the point *n*, through which the involute is drawn for the back of the tooth; which is limited at the top by a circle whose radius is *hd*, and at the bottom by one whose radius is *gb*, taken from the right-hand diagram; in which it is also seen that a curve

must extend from c to d, and another from a to b, each of which will be a sort of helix, lying however upon a concavo-convex surface instead of a cylindrical one.

An outside view of a complete tooth, greatly enlarged, is given below, where $t'n'$ is an arc of the pitch-circle, and the dotted outline $a'c'p's'$ is the section of the tooth by the plane LL; $e'n'$ is $\frac{1}{12}$ the pitch, $b'n'd'$ the remote contour of the tooth. The contour on the nearer side of the wheel is a similar curve $i'm'k'$, $e'm'$ being equal to $e'n'$; and $k'c'd'$, $i'a'b'$ are the quasi-helical curves above mentioned. Points in these curves might be determined by drawing other normal cones inside of OVL, and repeating the process just described, by which k' and d' were located; but for ordinary purposes of representation this is needless, the limitation being already quite narrow: thus, for instance, the upper curve must be tangent to $p'c'$ at the point c'.

At the opposite side of the tooth $r's'$, $r't'$ are also each $\frac{1}{12}$ the pitch, and the same curves are drawn in the reverse direction, of which $x't'u'$ alone is visible.

234. Indeed, few of the curves above discussed are actually seen in the front view of the worm-wheel, as shown in Fig. 159. But it is necessary to determine them nevertheless if it is required to construct the side view, as will be clearly seen by aid of the letters, which correspond with those of Fig. 158.

All the teeth must first be drawn in the end view, as was the case with the bevel-wheel: the points of their outlines lie upon circles which appear in the side view as straight lines, to which they are projected one by one from the end view.

As in the cases of the spur-wheel and the bevel-wheel, it is wholly unnecessary for the purposes of construction to make these outside views of the worm-wheel, which involve so much labor: for illustrations of the working drawings for the shop, the reader is referred to Part II, Fig. 18.

235. Drawing of a Screw-propeller.—Fig. 160 shows the hub and one blade of a screw-propeller, of which three views are given, viz.: on the right, a view from the starboard side of the vessel, at the left of which is a view from aft, looking forward, and above this is placed the top view. The subject chosen for illustration is a *true screw*, that is, one whose surface is, like that of the familiar square-threaded screw, generated by a right line all of whose points describe true helices of the same pitch; and in this case it also remains always perpendicular to the axis: the pitch being assigned, any one of these helices is readily drawn. The element oo, in the central transverse plane of the hub, is assumed to be vertical: then the intersection aob of the acting face with the hub is determined, and the intersection awb of the back is assumed, as in Figs. 126 and 127.

This being done, the blade is otherwise limited as follows: A definite distance x, aft of the hub, being assigned, a plane pp is drawn perpendicular to the axis, which fixes the overhang of the trailing edge; also the radius of the small circle whose centre is 1 being given, an arc is described with that radius, tangent to pp and to po the outline of the cylinder whose diameter is that of the screw, and ac is drawn tangent to this arc. Also, a distance od is assigned, and bd drawn, to fix the overhang of the leading edge; an arc with given radius being now described, tangent to od and bd, the dotted line $ayeozb$ is the contour of a box, as we may say, within which the propeller is required to revolve.

236. The problem then is, to determine the intersection of the acting face with this peculiarly shaped surface of revolution.

Suppose the vertical element *oo* to advance without rotating to the position *uu* in the side view: it would then cut *ac* at the point *v*, whose distance from the axis is the same as that of *j*. But while thus advancing, the element in fact does turn, so as to assume the radial position *uu* in the end view; describe about *C* an arc with radius *Cj*, cutting this radius *uu* in *g*, which will be a point in the intersection. By repeating this process any number of points may be located, and the apparent contour of the blade fully determined. Since the ratio of

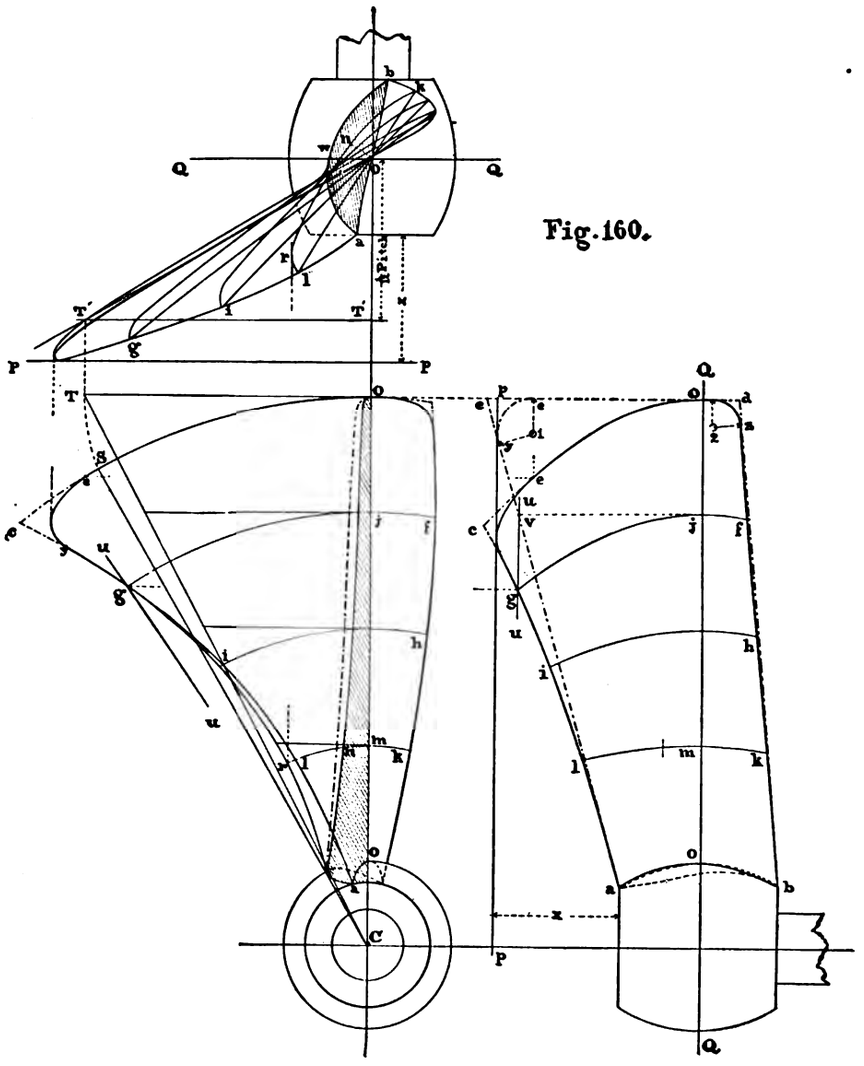


Fig. 160.

the rate of advance to that of rotation is constant, it will expedite matters to operate systematically, drawing a number of equidistant vertical lines in the side view and corresponding equidistant radii in the end view: a similar system of parallels in the top view will permit the projections of these curves to be worked out simultaneously in the three views, which is advantageous not only in saving time, but in serving as a check upon the accuracy of the construction, which is one of considerable delicacy.

237. In the top view the junction of the body of the blade with the hub is indicated by

sectioning, as in Fig. 127,—just as if the whole blade had been turned off in the lathe, leaving a mere film projecting. For the purpose of more clearly indicating the manner in which the thickness of the metal is gradually reduced as we recede from the centre and approach the thin edge at the periphery, intermediate sections of the blade are also shown in this view. These are sections, not by planes, but by cylinders—appearing in the end view as the circles *fg*, *hi*, *kl*, and in the side view as the correspondingly lettered helical arcs; in a word, they represent successive stages in the supposed process of turning off the blade. The sections of the acting face of the blade by these cylinders are therefore true helices, an aid to drawing which in the top view will be found in first determining the tangents at *o*. A convenient method of doing this is to draw at *o* in the end view a tangent to the periphery, and upon it to rectify a convenient fraction *oS* of the circumference, thus determining *oT*: in the present case the fraction selected was one twelfth. Then in the top view draw a parallel to *QQ*, at a distance from it equal to the same fraction of the pitch; to this line *T* is projected from the view below, and *To* thus determined is tangent to the outer helix. In the end view draw *CT*, and intersect it by tangents to the other circles, *fg*, etc., by which the sections are made: the points thus found, projected to *T'T'* in the top view, will be like manner lie upon the tangents to the other helices.

238. These cylindrical sections then are bounded in front, that is to say, on the acting face, by helices. The lines bounding them on the back cannot be determined by any fixed rule: they are in fact commonly drawn arbitrarily to a great extent, the leading edge being always, however, made thinner and sharper than the trailing edge, because in the main the propeller is used for going ahead and not for backing. But as a further guide to the distribution of the metal, it is a common practice to put in the end view, as shown in full lines, what is called a "conventional section." This is not a true section by the plane *QQ*, however, which would give to the back of the blade a form like that shown in the dotted line: the conventional section indicates the required *normal* thickness of the metal at points upon the vertical element *oo*. From this we may derive a little assistance in constructing the back lines of the cylindrical sections; thus, for instance, the circle *kl* cuts *oo* at *m*, and the line of the conventional section at *n*; in the top view set off *On* equal to *mn*, in a direction normal to the helix *lok*: then *n* is one point in the corresponding back line *lrnk* of this particular section, and a like determination is to be made for each of the others.

239. In the end view the contour of the leading edge is the curve *khf*, beyond which nothing is visible. The outline of the trailing edge is the curve *aligy*; but the thickness of the blade at its junction with the hub and for some distance outward is so great that the back, it is obvious, can be seen beyond the trailing edge. And the cylindrical sections will enable us to ascertain its contour: for example, draw parallel to the axis a tangent to the curve *knl*; this line is an element of the cylinder, and touches the curve at some point *r*, which is projected to the circle *knl* in the end view, thus locating a point in the required visible outline of the back; as many more as desired may be found in like manner.

240. Since the back lines of the cylindrical sections are, substantially, assumed, it must be admitted that there is no absolute certainty that the surface of the back will be "fair," that is, free from humps or hollows. To make certain of that, it would be necessary to make such sections quite close together, and also a series of sections by transverse planes,

also close together, and to alter the lines until the two sets were not only concordant, but composed of fair lines throughout. This, however, it is needless to do unless a *pattern* is to be made in exact accordance with the drawing. Such propellers are usually made by "striking up" the face in loam; this done, a sort of pattern in sand is constructed upon it, the back of which the moulders fashion with their trowels: this is used to make a mould for the back of the blade, and then destroyed.

When this course is pursued, a drawing such as has been described serves every purpose.

241. The appearance of the complete propeller with four blades is shown in Fig. 161. In

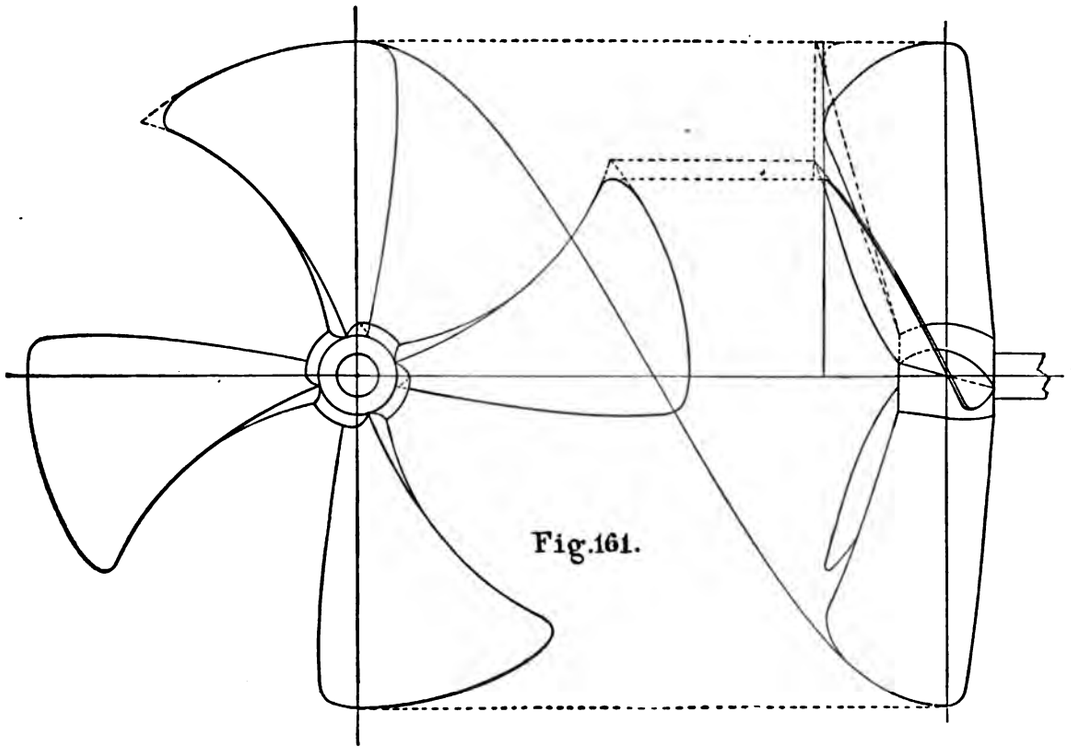


Fig. 161.

relation to this it may be said that the placing of the two views at such a distance apart as to include between their vertical centre-lines just one half the pitch, is rather fanciful perhaps. Still, when the proportions are such as to make it convenient, the opportunity thus afforded to represent in an appropriate position one half of the outer helix may well be utilized to convey graphically an idea of the proportion between the pitch and the diameter of the screw,—which can hardly be done in a more effective manner than that here adopted.

242. In conclusion, a few words may be said in regard to certain modes of sectioning. It is by some laid down as an absolute rule that the section-lines should be inclined to the outlines at an angle of 45°. But if this be adhered to in the case of a long and thin piece, the effect, as any one can satisfy himself by trial, will be very unsatisfactory; an angle of 30° with the longer side will produce a much more pleasing effect, and will, besides, require fewer lines and consequently less time.

In the representation of work composed of rolled plates, such as boilers, the details of

iron ships, and the like, the most effective as well as the most expeditious method is to rule the sections with fine longitudinal lines, as shown in Fig. 162.

But if such work is to be drawn upon a small scale, it will often happen that the attempt to represent the thickness of a sheet of metal by even a double line is not only laborious, but unsuccessful. In such cases a very telling and comparatively easy expedient is shown in the lower part of 162: the whole area of the sectioned parts is filled in with solid black, care being taken to show the joinings by leaving a fine line of pure daylight between the surfaces which are actually in contact. Fig. 163, which exhibits the side armor of an iron-clad vessel of the Monitor type, is an example of the effectiveness of this style for certain purposes in producing emphatic contrasts and making conspicuous the important features. But, obviously, contrasts so violent as this are suitable only for drawings made on comparatively small scales.

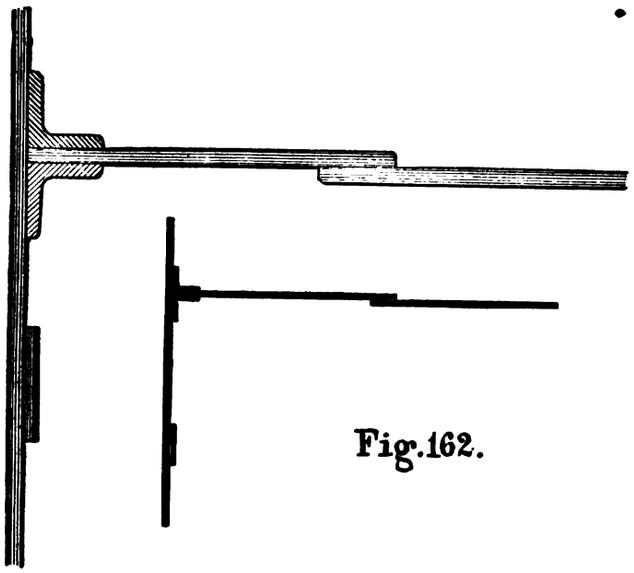


Fig. 162.

243. It was stated in (**15**), that in sectioning the aim should in general be to imitate the effect of an even tint covering the surface, so transparent as not to obscure the dotted outlines of parts beyond, and therefore of necessity too light to impair the distinctness of the lines defining its own boundaries. It is not imperative that the spacing should be the same throughout: if any pieces are small they may be, and if quite small they must be, sectioned more closely than the larger ones, though with lines a trifle finer; nor will this make them unduly prominent, nor destroy the general effect of uniformity in the tone. This of course has reference to the finish only, and is upon the supposition that the ultimate object is to produce the most agreeable effect; the fact that certain portions are cut is distinctly shown, but no information as to the materials of the structure is conveyed.

That information is of course essential to the completeness of a working drawing, and it may be conveyed in more than one way. In the days when, before the invention of the blue-print process, tracings were sent into the shop, one mode of indicating the different substances was by the use of colors, wrought-iron for instance being sectioned in blue, cast-iron in black,

composition metal in red, and so on. This had the advantage of making the distinctions clear and conspicuous, without impairing the even and finished effect.

244. Colors being inadmissible when blue-printing or kindred processes are employed, the practice has obtained to some extent of sectioning different materials in different styles, with an effect upon the appearance of the drawing as a whole which in most cases it would be gross flattery to call hideous. An effort has been made to secure general adoption of some uniform system or standard in regard to this, but as yet without positive results. In Fig. 164 we give a few specimens selected from the series arranged by Mr. Frank Van Vleck in

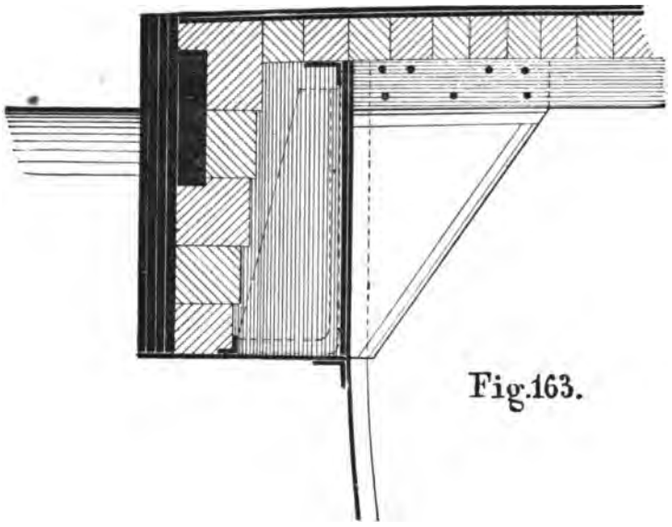


Fig. 163.

furtherance of that effort;*—a series probably as perfect and as free from objections as any that could be devised. The materials are as follows:

A. Wrought-iron.
B. Steel.
C. Wires.
D. Stone.
E. Brass.
F. Brick.
G. Cast-iron.
H. Wood.
I. Babbitt-metal.
K. Vulcanite.

Aside from the ruinous effect of this method upon the appearance of the drawing, which may be regarded by many as of slight importance, it appears open to one or two serious practical objections. It is not easy to do the sectioning well in such styles, for instances, as those shown in *A*, *B*, *E*, and *K*, and it is impossible to do it rapidly, which is in many cases of considerable importance; again, absolute dependence upon any system would demand perfect familiarity with the adopted code of symbols on the part of all the workmen for whose guidance the drawings are made.

* See *American Machinist*, April 9, 1887.

245. This last would apply with equal force to the use of colors, and indeed it appears in any case advisable to make use of reference-letters, of which an explanation should be written upon each sheet, as, for example,

a, *a*, Cast-iron; *b*, *b*, Wrought-iron; *c*, *c*, Steel, etc.;

and then let each piece be marked with the proper letter, according to the material of which it is to be made. This course, which is both simple and certain, was extensively used even

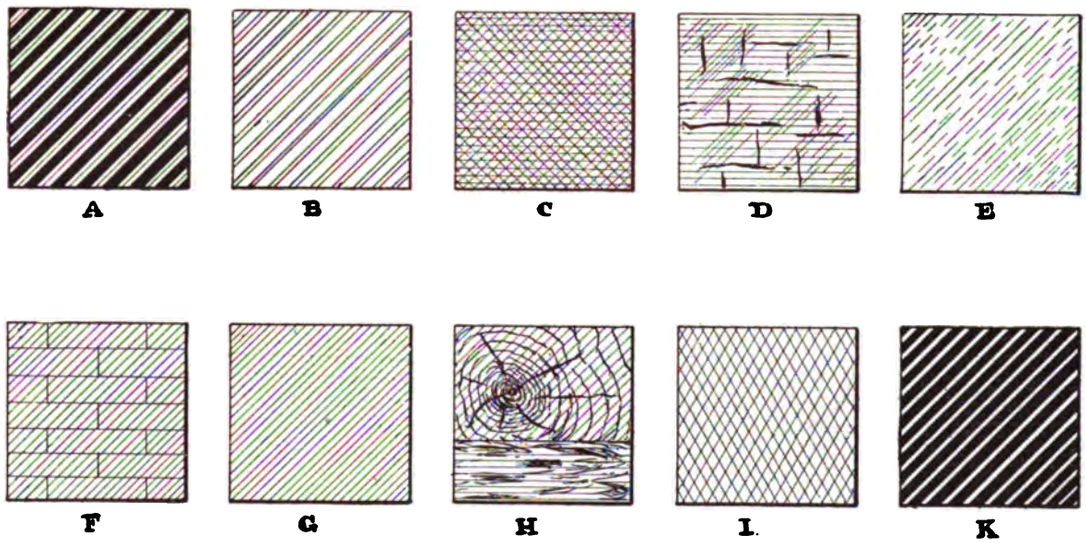


Fig. 164.

when the sectioning was done in colors: it is equally applicable if the whole drawing is made in plain black, thus enabling the draughtsman to avoid the unpleasantly variegated effect of the proposed standard sectioning, and to produce results rivalling in harmony of tone those of a well-executed engraving.

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PRACTICAL HINTS

FOR

DRAUGHTSMEN.

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PREFACE.

THE leading object of this treatise is to explain various modes of representation which are in many cases better than the precise ones of projection; for mechanical drawings often convey false impressions by too close adherence to the truth, and become obscure by being too exact.

All working plans are made for the purpose of showing what is to be done, and should exhibit the maker's knowledge, not of the refinements of theory, but of the requirements of practice. They are to a considerable extent beyond the jurisdiction of the rigid laws of descriptive geometry, and to that extent they lie within the domain ruled by plain common-sense. This fact is often not duly impressed upon the mind of the student; which is unfortunate, because no one thing is more fatal to practical efficiency than the strict formalism which subordinates the end to the means, allows no exercise of discretion, and binds the draughtsman to the observance at all times of inflexible rules.

It is hoped that the reader will escape such thraldom in either constructing drawings to scale or making sketches; both of which are illustrated by a number of practical examples of approved methods.

The addition of the chapter on drawing instruments is justified by the fact that in most treatises upon drawing, mere descriptions or illustrations are given, with nothing to guide the novice in distinguishing the good from the bad; and also by the reception of numerous letters of inquiry, from those desirous of information upon this very important and much-neglected matter.

C. W. MACCORD.

HOBOKEN, N. J., August 22, 1887.

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CHAPTER I.

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CHAPTER I.

WORKING DRAWINGS DEFINED. RULES OF PROJECTION DEFIED. CLEARNESS AND CERTAINTY THE ESSENTIAL REQUISITES. ILLUSTRATIVE EXAMPLES.

1. Mechanical Drawings are made in the main according to the principles of projection, which constitute a part of the science of descriptive geometry; but even a perfect acquaintance with that science will not of necessity or of itself make its possessor an efficient practical draughtsman, no matter how skilful he may also be in the manipulation of the instruments.

The object of working drawings is, *to show the workman what to make and how to make it*, which they should do in a distinct and unmistakable manner. And it is amply proved by experience, that drawings may be in themselves absolutely correct, and fail nevertheless to accomplish this object. The meaning may be there; but if it is not clearly and forcibly expressed, the work is radically bad, though never so finely executed.

Other things being equal, he is the most valuable man in the drawing office who can with the least outlay of time and labor produce such work as will enable the construction to be carried forward with certainty and dispatch. To this end his drawings must be easily read and well arranged; it will not suffice, as many suppose, that they be correct as studies of projection. It is well that the draughtsman should be master of the principles of his science, but in the practice of his art he should not be their slave; perspicuity is as important as accuracy, and judicious defiance of rigid rules will often result in a gain in this respect as well as in a saving of time.

2. It is mainly to such irregularities that the following pages are devoted; supposing the reader to be already familiar with the laws of projection, it is proposed to show how and when those laws may be broken with impunity.

This cannot be done wholly by laying down specific instructions; it would be difficult if not impracticable so to classify exceptions as to deduce from them rules that would cover the whole ground, or be of universal application. New devices and new combinations are continually arising, special features of which may require special treatment, and there is constant occasion for the exercise of judgment and ingenuity.

The general plan adopted therefore is, to illustrate the matter by a number of

examples selected from practice, explaining in each case the particulars in which it violates the strict canons by which so many submit to be fettered, and showing the advantages thereby secured.

3. For the guidance of the workman, there are required *detail drawings*, showing the construction of the different parts, and a *general plan*, showing these parts assembled, or put together.

If a machine is to be manufactured by the quantity, with interchangeable parts, a separate drawing is usually made of each individual piece, large or small, with all the dimensions accurately marked in figures. And the idea is to some extent prevalent that this is always necessary, and that the draughtsman's work is not complete without it.

But the term detail drawing is also used in another sense. Suppose the case of a constructing engineer designing the machinery for a steamship. He must furnish to the building shop, certainly, drawings from which the engines can be made as he plans them, but in his detail sheets he need not dissect so minutely as above indicated. A drawing, for instance, of the connecting rod, showing it keyed together as when in place, is as properly a detail drawing as though the shank, brasses, gibs, keys, straps, bolts and set-screws were disconnected and scattered broadcast over the paper. It is indeed a better working drawing, since with a fraction of the labor it explains more, showing both how the different pieces are made and how they are related to each other and fitted together.

4. It is in this broader sense that we use the expression *detail* drawings, as distinguished from what might more accurately be called the *detached* drawings mentioned above. The former are always necessary, whether the others are required or not; he who can make them can always make the others on occasion; and the more skilfully he can make them,—the greater his ability to *condense*, and to reduce the number of sheets,—the more efficient will he be, and the more expeditiously can he "put work in hand" in cases of emergency. They are in effect both "general" and "detail" drawings for the members of the machine, and are all that the designer need furnish to the constructor, who is at liberty to follow his own judgment as to further subdivision.

5. General plans, as above stated, are intended to show how the various parts of the machine are arranged and put together as a whole.

They are too often made upon the assumption that in each view it is necessary to introduce every piece that would be visible, partially or wholly, in the corresponding view of the machine itself. The effect is sometimes more confusing than explanatory, and in the majority of cases a great many minor details can be omitted not only without detriment, but with a great gain in perspicuity. This is more especially true as to bolts and nuts—the fastenings must of necessity be shown in the detail drawings, and usually a repetition of them is worse than useless.

6. No rule can be laid down as to how many views should be made, or what views they should be; these points must be decided by common-sense and good judgment, aided by experience. But there can be no greater mistake than the too common deduction from a study of projections, that a front view, an end view and a top view are always required and always sufficient. No pains should be spared to

make drawings clear, and the meaning unmistakable: this must be done at any cost, but all beyond that is superfluous and a waste of time. If one view will answer the purpose, so much the better; but if a dozen are necessary, they must be made. Before sending out a sheet, let the draughtsman satisfy himself that the representations and annotations are such that by following them *the workman can make what is intended, and cannot make anything else;* then, and not until then, his working drawing is complete; and in a practical sense correct, no matter how numerous or flagrant the violations of theoretical formality.

7. As before intimated, it is not easy to frame a definite code of laws for guidance in breaking those of another code; because the circumstances which justify the breaking of any one may vary in different cases. But it is possible to indicate some, at least, of the articles of that code, the ignoring of which is likely to be most frequently recommended. Among these are the following:

(1) That all the things shown in any drawing must be represented in all the different views, as preserving the same absolute and relative positions.

(2) That everything visible in one view of a drawing, must also be shown in every other view.

(3) That in sectional views the cutting plane should be parallel to the paper.

(4) That everything should be shown in section, through which the cutting plane in a sectional view would pass if indefinitely extended.

(5) That everything beyond a cutting plane should be shown.

8. And in opposition to these in their order, the following general principles may be enunciated:

(1) That in each separate view, whatever is shown at all should be represented in the most explanatory manner.

(2) That which is not explanatory in any one view may be omitted therefrom, if sufficiently defined in other views.

(3) The proper position of a cutting plane is that by which the most information can be clearly given.

(4) It is not necessary to show in section everything which might be divided by a cutting plane.

(5) Whatever lies beyond a cutting plane may be omitted when no necessary information would be conveyed by its representation.

9. In what follows, no attempt has been made to observe the above order in arranging the illustrative examples. That could not well be done, for the reason that in many of them more than one of these principles is involved, as well as others of less moment not here enumerated. They are accordingly given, rather in the order of the relative importance of the special methods of representation which are recommended.

And these, it is proper to say, are such as have not only received the sanction of the highest authorities, but have stood the test of trial and of use; for they have been continuously employed, during years of practice, in the preparation of drawings from which machinery to the value of many millions has been constructed.

PRACTICAL APPLICATIONS OF THE FOREGOING PRINCIPLES.

EXAMPLE I.

10. We select as the first subject for illustration, an upright cylinder fitted with a cover. A vertical section of both, and a top view of the cover, are given in Fig. 1.

Let it be noted, first, that in the top view the ***bolt-holes*** only are shown, the nuts being omitted.

The section is by the plane *ab* through the axis; which passes through a bolt at *d* on the right, and midway between the bolts *c* and *e* on the left.

But it is to be noted, secondly, that the sections of both cylinder and cover are made continuous, as though there were no bolts, and the bolts themselves are then dotted in; and, thirdly, that on each side, the centre line of the bolt is placed *at its actual distance from the edge of the flange.*

11. One important precept is here illustrated, an exception to which is very rarely met with, viz.: *The continuity of masses of metal should not be broken for the purpose of showing fastenings.*

In this example, the conveying of the idea of the construction as a whole depends more upon showing at a glance the thickness and the breadth of each flange, than upon any other one thing.

The cylinder and the cover must be fastened together, and the bolts are made for that purpose; but being subordinate, they should not be made unduly prominent.

A very common and very faulty method of drawing the sectional view in such cases is shown at *A*, upon which the makers insist, because, they say, the bolt lies in the plane of the section.

But the effect is very much as though the bolt thus brought into notice were the important feature, and the cylinder and its cover made chiefly for the purpose of using it. Still worse, two little portions of the flanges are thus isolated, like islands lying off a headland, and the main idea is neither as clearly nor as forcibly expressed as it is in the method recommended, while the labor is greater.

Again, it is very common to see the *nuts* carefully drawn in the top view; and projected to their corresponding positions in the side view, as also shown in *A*. The whole of this is a sinful waste of time. If the kind of bolt, its size, its true position in the flange, and the form of the nut, are shown in the section, there is no use of showing the projections of the nuts beyond the plane of the section; and if the number and arrangement of the bolt-holes is shown in the top view, there is no use of drawing the nuts.

12. A vast amount of time and labor are in many cases worse than wasted in just

such apparently small items as these; and we wish to impress upon the reader this maxim, *that each view should be made to tell all it can, but nothing should be put in it which does not tell something worth knowing.*

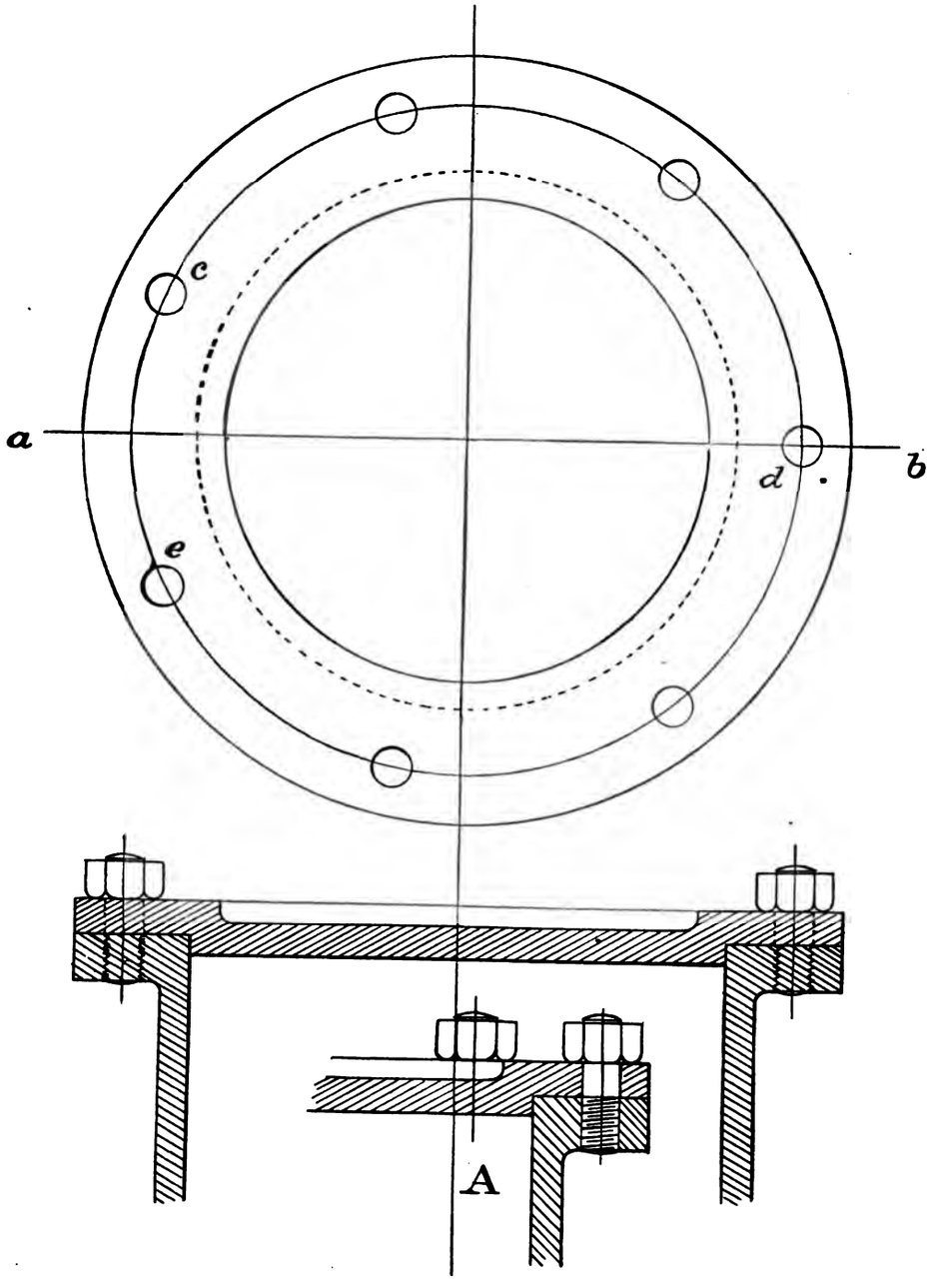

FIG. 1.

Another illustration of the disadvantage of giving too great prominence to the fastenings is given in Fig. 2, which shows one arrangement of a double-riveted joint between two sheets of wrought-iron. If the rivets are shown in full, each sheet is cut

into three detached parts in the sectional view, and the extent of the lap, which is the feature of prime importance, instead of being made to catch the eye at the first glance, is thrown quite into the shade, and requires a little mental arithmetic for its full realization.

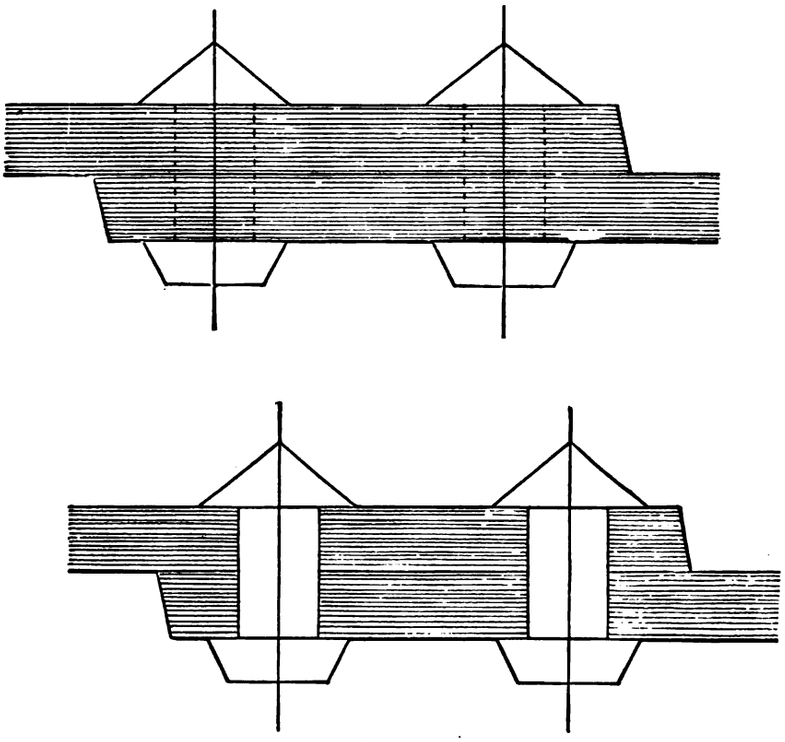

FIG. 2.

It must also be recollected that in studying a drawing, the designer himself will find it greatly to his advantage if the relative proportions of the parts are made as conspicuous as possible: and in the representation of bolted or riveted joints nothing could be devised which would make them *less* conspicuous than to cut the joined pieces into little bits, in the style here condemned.

EXAMPLE II.

13. In Fig. 3 is shown a vertical cylindrical box, divided transversely for a part of its depth by a web upon which are formed two hubs, through which bolt-holes pass, and provided with four lugs perforated for holding-down bolts.

In the top view the lugs are disposed diagonally with reference to the main centre lines; this being the position which the piece is to occupy when in place. In order to show the true diameter and thickness of the cylinder in the section, the cutting plane should pass through *ab*: in that case it would also cut the dividing web.

And too often the position is meekly accepted, the web cut through and the outlines

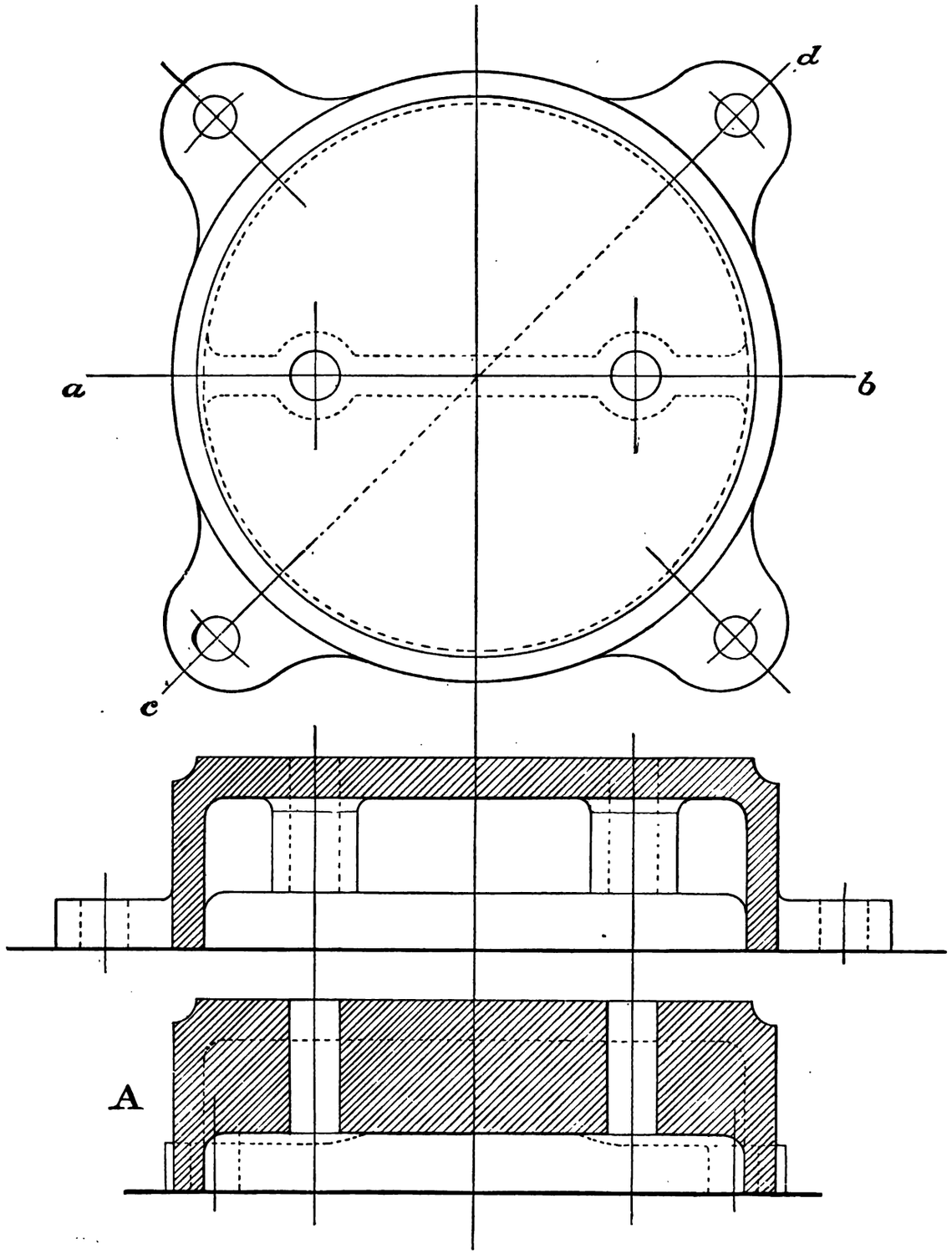

FIG. 3.

of the bolt-holes drawn in, separating the mass into three parts; and to cap the climax the lugs are projected and dotted in, with all the obscurity attendant thereupon. As a good specimen of bad judgment, and as a warning to the reader, all these enormities are represented in section *A*.

The proper course is to back the bull off the bridge, in all similar cases. The true diameter and thickness *are* shown in the section, but an outside view of the web and its hubs is given, as though they were beyond the cutting plane. Moreover, the lugs are shown in external elevation, just as though the line *cd* were turned around the axis so as to coincide with *ab*; thus the centre line of the lug-bolt is shown at its true distance from the axis.

And the result is, that in spite of, or rather by reason of, these discrepancies between the views considered as studies of projection, a much clearer idea of the structure is conveyed by the sectional view, while the relative positions of the different parts is shown in the top view, so that with the two before him the workman cannot find an excuse for an error.

It may be stated as a general rule, then, that *a web parallel to the paper should not be shown in section*, even though a plane cutting other parts which must be so shown, should be so situated as to pass through the web.

EXAMPLE III.

14. Fig. 4 represents a portion of a horizontal cylinder upon the lower part of which is cast a supporting bracket. This bracket consists of a foot-plate, connected with the cylinder by two vertical webs at right angles to each other. At the end of the cylinder a hub *H* is formed, which is drilled and tapped for a drain-cock.

This example illustrates, as did the preceding one, the maxim just laid down, for the vertical plane *xy* really cuts through both the hub *H* and the longitudinal web of the bracket;—but neither is shown as being cut, in the longitudinal section.

The form of the foot-plate, and the positions of the holding-down bolts, are clearly shown by a horizontal section through *ab*, placed directly under the bracket. Similarly, the form of the hub is shown by a section through *cd*.

Again, the transverse cutting plane *wz* is so situated as actually to split the central cross web, which accordingly is *not* drawn in section.

Notice is also to be taken of the fact that since the hub *H* is fully explained by the two views of it above mentioned, it is not dotted in behind the bracket in the transverse section, although the cylinder flange is. This flange is thus shown, not so much because it is necessary in order to define its form, as for the purpose of exhibiting the arrangement of the bolt-holes; there being a bolt on the vertical centre line, opposite the hub, the hole for it must be tapped, as indicated by dotting *two* circles, one for the bottom and the other for the top of the thread.

This being an important consideration, and a thing which could not be otherwise shown in these views, affords another reason for omitting the representation of the hub, which if introduced here would obscure this bolt-hole by the confused mass of dotted lines.

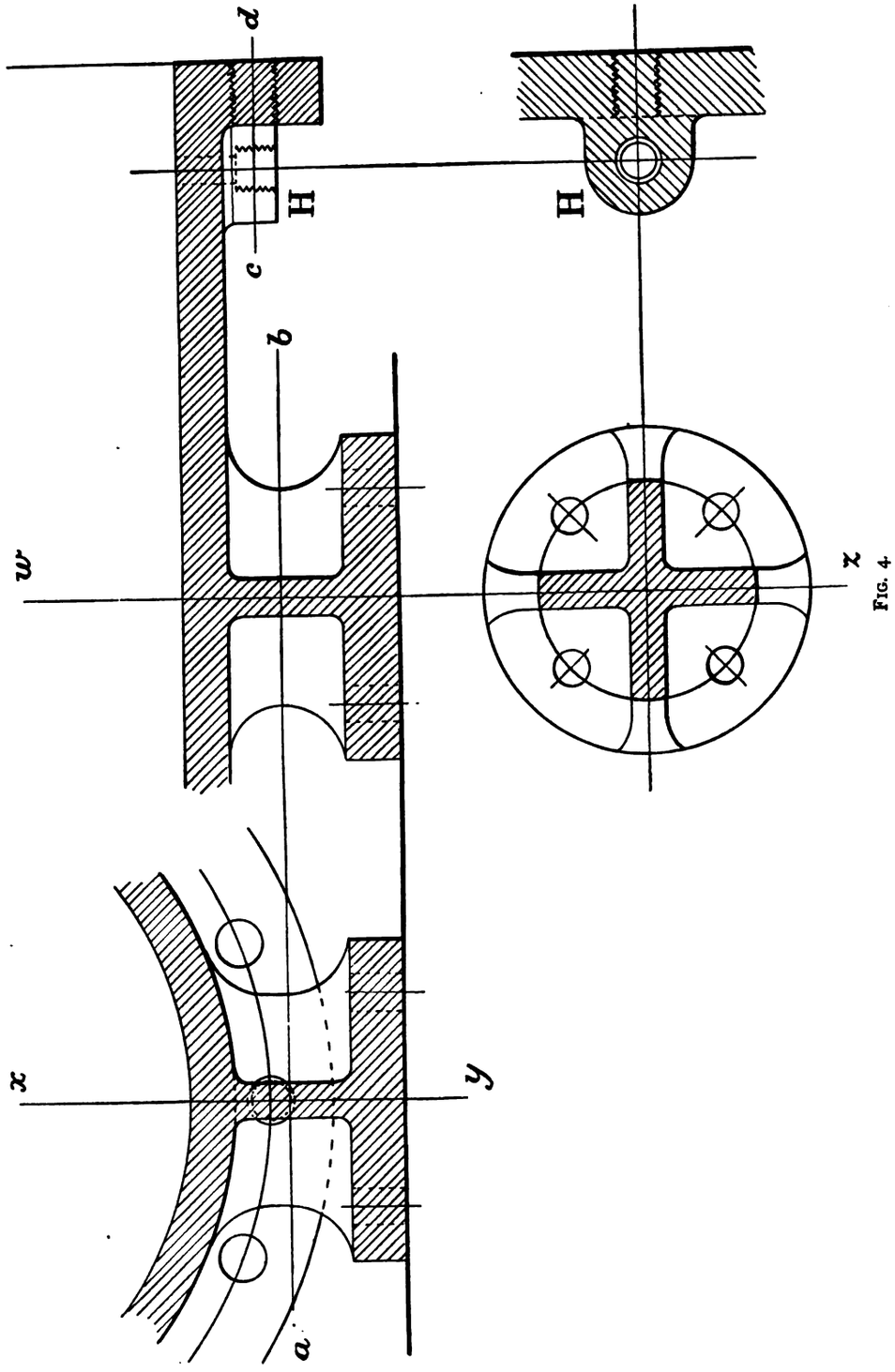

FIG. 4.

EXAMPLE IV.

15. The next illustration, Fig. 5, is that of a simple pulley or drum, consisting of a rim connected with the hub by a web, and secured upon the shaft by a key.

In the end view, the shaft and key are brought out most distinctly by showing them in section, as though cut off flush with the end of the hub by the transverse plane *ab*.

The other view is in the main a section by the plane *xy*. The shaft, however, is not shown as cut through, nor do we think it ever would be unless it were hollow, as is sometimes the case, or possessed some other peculiar feature which would call for such a course.

But it is to be noticed that this drawing shows the key dotted in as though it lay

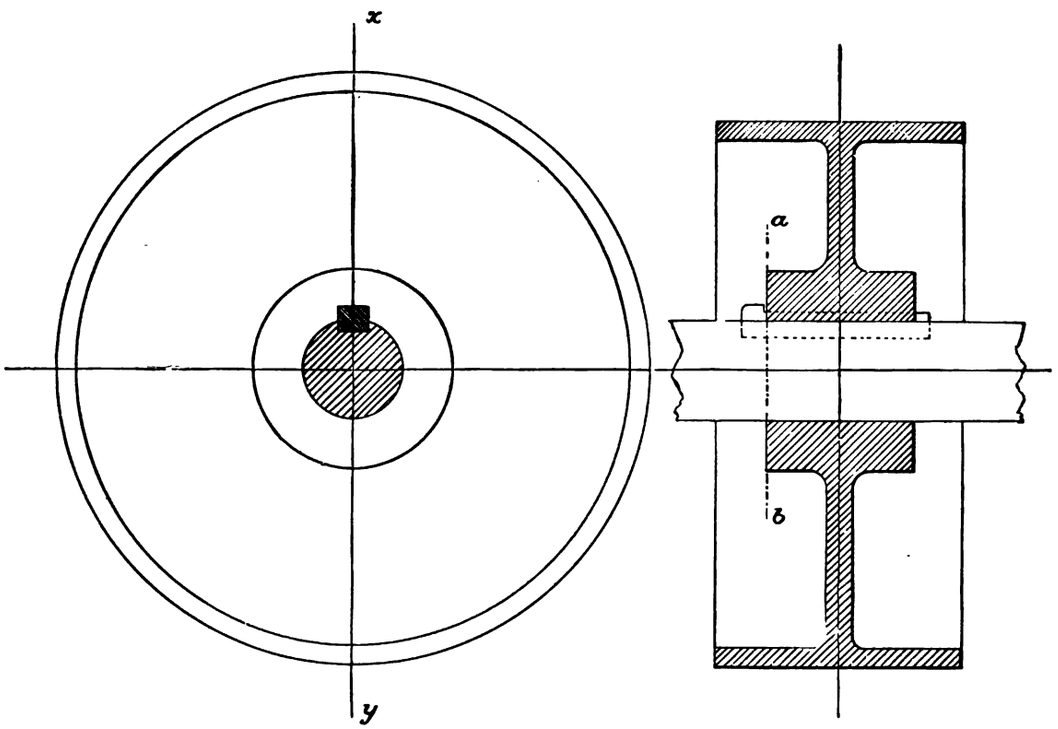

FIG. 5.

beyond the cutting plane. A very common fault is, to draw the upper part of the key, which is outside the shaft, in full, as well as the shaft itself.

In that case the sectioning of the upper half of the hub terminates at the upper outline of the key; and the effect is that the whole appears lop-sided, as though the hub were eccentric, or thinner on one side than on the other.

It may be urged that this can lead to no error, since all is explained by the end view. The truth of this argument we freely admit; but there can be no good reason why that false impression should be conveyed by either view.

And we shall have occasion to illustrate in other examples the maxim, which is of no small moment sometimes, that *if a thing be symmetrical, it should be represented as symmetrical in every view if possible.*

EXAMPLE V.

16. Fig. 6 shows two hand-wheels, one having four straight arms, the other three curved ones.

It is particularly to be noticed that the longitudinal section is the same for both, and if *xy* be regarded as the cutting plane, it does not represent the appearance of either. But it does show exactly what the workman wants to know, viz., the forms of the sections of the rim and of the hub, the thickness of the arms at the hub and at the rim, and the sizes of the side fillets at the ends of the arms. In the case of the wheel with the three curved arms, a true section by the plane *xy* would show the upper side of the rim and of the hub with an unsightly and unsymmetrical excrescence, which, if not unintelligible as well, would at best convey no information except that the

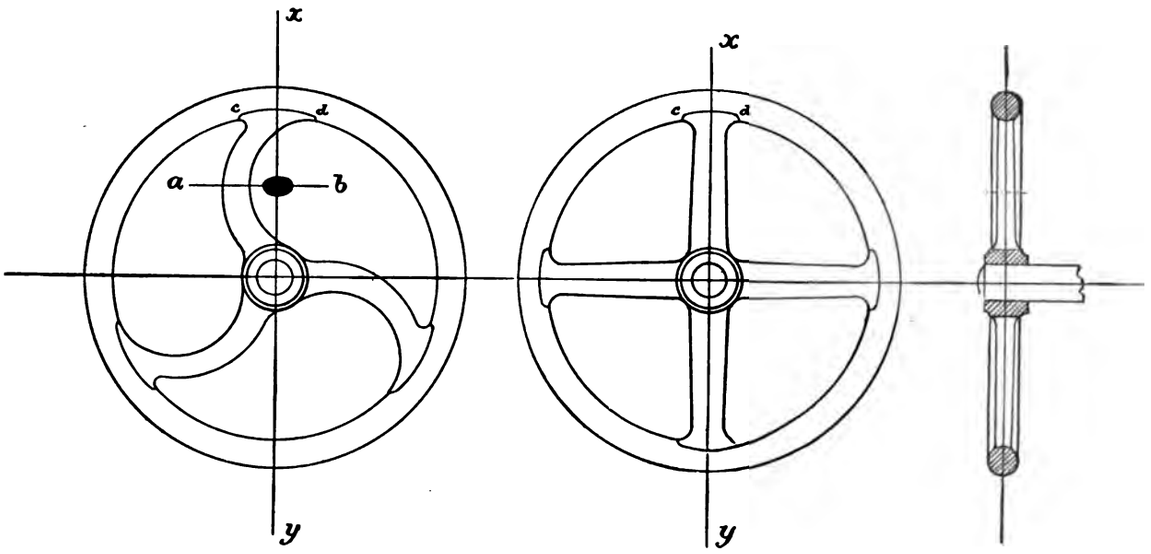

FIG. 6.

draughtsman knew how to make the section: and the same may be said of the foreshortened projection of the lower arm and its junction with the rim.

In the case of the other wheel, a true section by the plane *xy* would at first glance convey the impression that hub and rim were joined by a continuous web. Closer study would rectify the error if the outlines of the hub and the rim were completed by dotted lines: still, that is not a good reason for making a drawing which can possibly convey such an idea, when it is easier to make one which can not.

17. The form of the arms is explained by making a transverse section of one of them, as by the plane *ab*; this section should, as shown, be drawn at one side of the arm, and not directly upon it, as is sometimes done; a device apparently founded on the idea of "revolving the cutting plane about its trace into the plane of projection," but a very ineligible one: for it has precisely the appearance which would and should be presented if the arm had a piece cast upon it, projecting from the front side—such a piece could not be more effectively brought into notice than by sectioning it.

The fact that the arms, by reason of their thickness, do not join the rim entirely on the inner circumference, but encroach upon its breadth, is indicated in the front views by the curves *cd*.

These, it is to be observed, are not curves of *intersection* properly so called, but indicate the lines of tangency of the fillets formed at the ends of the arms and the surface of the rim.

Strictly, then, they are imaginary lines, and some worshippers of the Correct insist that they ought not to be drawn. But such evidences of things not seen will often define most clearly the substance of things hoped for: and when they will it may be as well to let them. In the present instance, and in others which will be met with subsequently, it is beyond dispute that the introduction of these imaginary lines, if drawn finely, is fully warranted by the service they render in making the drawing intelligible.

EXAMPLE VI.

18. Fig. 7 represents a crank, crank-pin, and a portion of a shaft, including a journal between two collars formed upon the shaft.

This is introduced here in further illustration of the use of imaginary lines, as being a case in which they are absolutely essential.

It is a well-known fact that if a crank-pin of the form here shown be made with a sharp corner at the inner face *ab*, like that at the outer face *cd*, it will be very liable to break there; and that the same is true if the junction of the shaft with the collars be made sharp, even if the angle be a right angle.

The liability to accident is very greatly reduced by rounding out, or, as it is called, "filleting," these angles, as shown in the drawing, the vertical lines being joined to the horizontal ones by quarter-circles.

If, as often happens, circumstances prevent the use of a long journal, it becomes necessary, in order to secure as much cylindrical bearing surface as possible, to make the fillets as small as may be; and very small ones are far better than none at all.

In such a case, especially if the drawing be on a small scale, the very existence of the fillet might be overlooked, were the line of tangency not drawn in. This renders such an oversight impossible, no matter how fine the line; and the finer it is the better the drawing will look.

Tastes differ in regard to the question whether this addition improves the appearance of a drawing; but the draughtsman whose experience includes the breaking of a shaft in consequence of its omission, will thereafter vote in the affirmative: the safe side is always the most comfortable.

It may then be stated that in general, though the rule has exceptions, *the fillet lines should be drawn in outside views of surfaces of revolution.*

This crank is shown as secured to the shaft by two keys, the positions of which are shown in the end view, which also defines the cross-section of the keys. The side view can convey no further information except as to the length of the keys; and this is as well done by showing only one of them, while it is clearer to place it in that view at the top of the shaft, which is accordingly done.

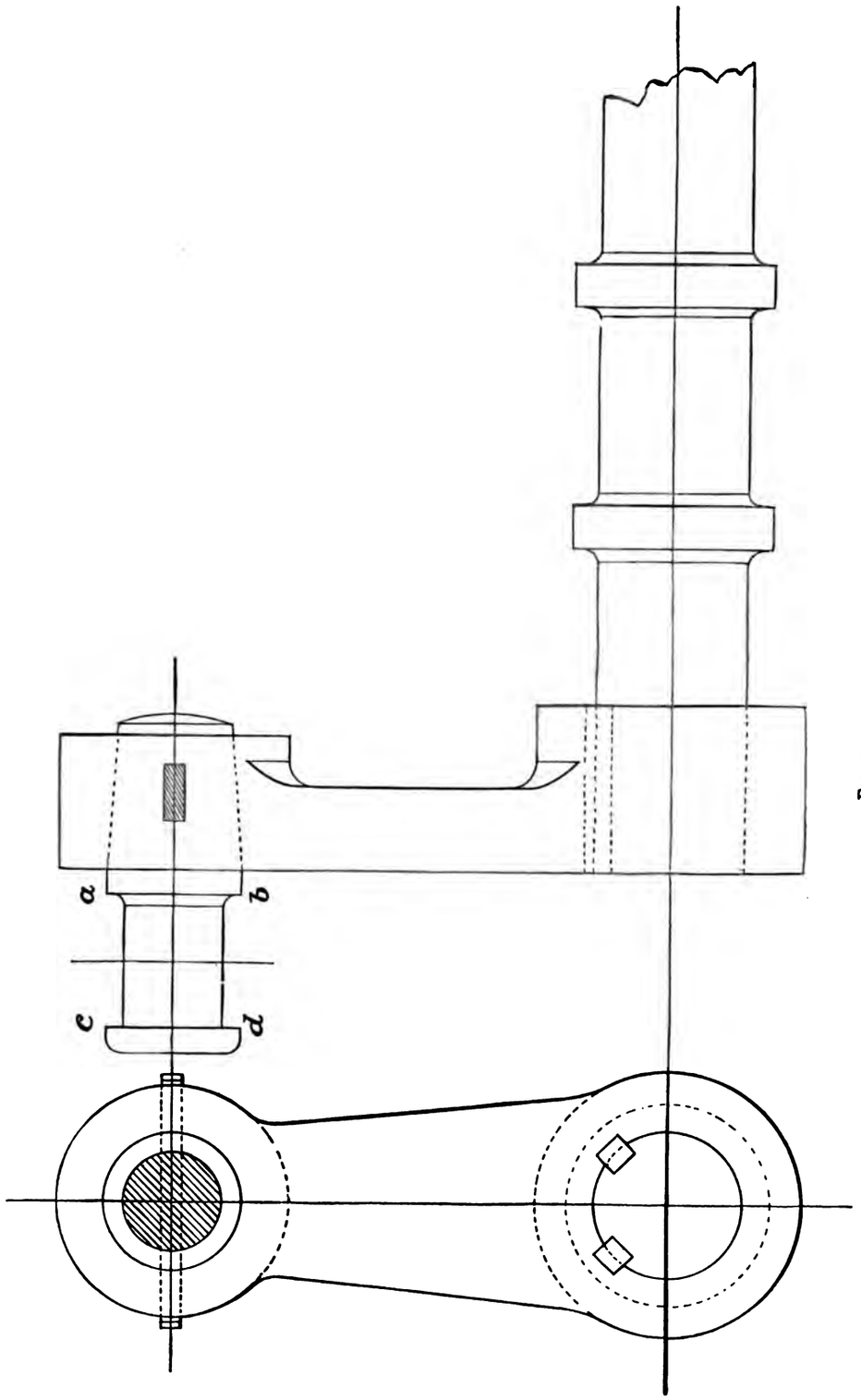

FIG. 7.

EXAMPLE VII.

19. A simple pillow-block, consisting of bed, cap, and bolts, without brasses. Fig. 8.

This example illustrates chiefly the selection of views. An end view of a pillow-block is often made, in addition to those given: but if it be in elevation, its only effect is to consume time in the drawing office without saving it in the shop. In pillow-blocks of more complicated construction, particularly if the brasses be hollow, or babbitted, or both, *a longitudinal section* may advantageously be added; in which case it is to be observed that the dotting in of parts beyond the plane of section, and concealed, is better omitted.

In the present instance, the side and the top view are all that are required. And in the latter, only the bed is shown; the cap and the bolts are removed.

It is sufficiently indicated by the lines in the side view, that the form of the cap corresponds to that of the top of the bed; and the bolts, with their heads and nuts, are fully defined in that view. By leaving these things out in the top view, we not only save the time that would be occupied in drawing them, but make the view clearer: as the form of the pocket in which the head of the bolt is buried, must be dotted in at any rate, which could not consistently be done without dotting in also the head of the bolt, and over this again would come the full outline of the nut. The effect, as a moment's consideration will show, would be to confuse this part of the work by superposition of lines. *Judicious omission is preferable to correct superfluity.*

EXAMPLE VIII.

20. An ornamental air-vessel, with an opening in the top, into which is screwed the plug *P*. This plug is itself bored out and tapped for the insertion of the pipes *T*, *T*. Fig. 9.

This exhibits a legitimate expedient for combining the advantages of a sectional view and an elevation. The general appearance and proportions of the air-chamber are best shown by an outside view, but the form of the interior, and the arrangement of the plug and pipes, if merely dotted in, would not be as distinctly seen as if drawn in section. The body and neck of the vessel are round; the bottom flange is square, as indicated by the shadow lines.

In sectioning over an outside view in this manner, the section lines, or cross-hatching, *should be full, and not dotted or broken;* the effect of this last is simply to make a confused mass of dots, while the effect which sectioning should have is that of a light tint, not heavy enough to overpower the outlines.

Dotted parallel lines which are close together have in all cases a very unpleasing and indistinct effect. In order to avoid this in representing the tube *T*, it is to be noted that the external outlines only are shown, except at the lower part. Here a section of the pipe is made, *in full lines*, just as though a portion of the wall of the air-chamber had been broken out, thus permitting the pipe to be seen. The actual execution of that

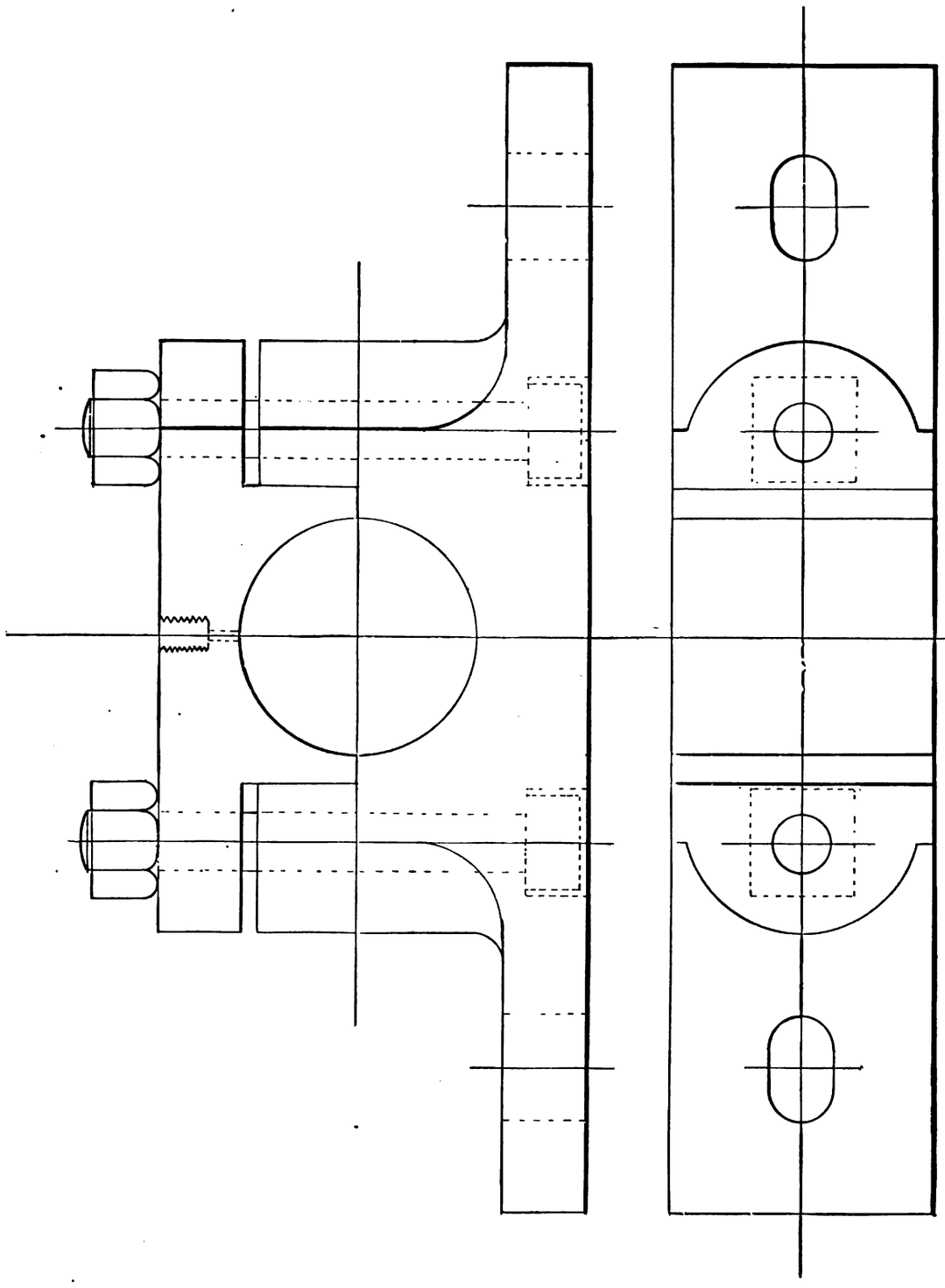

FIG. 8.

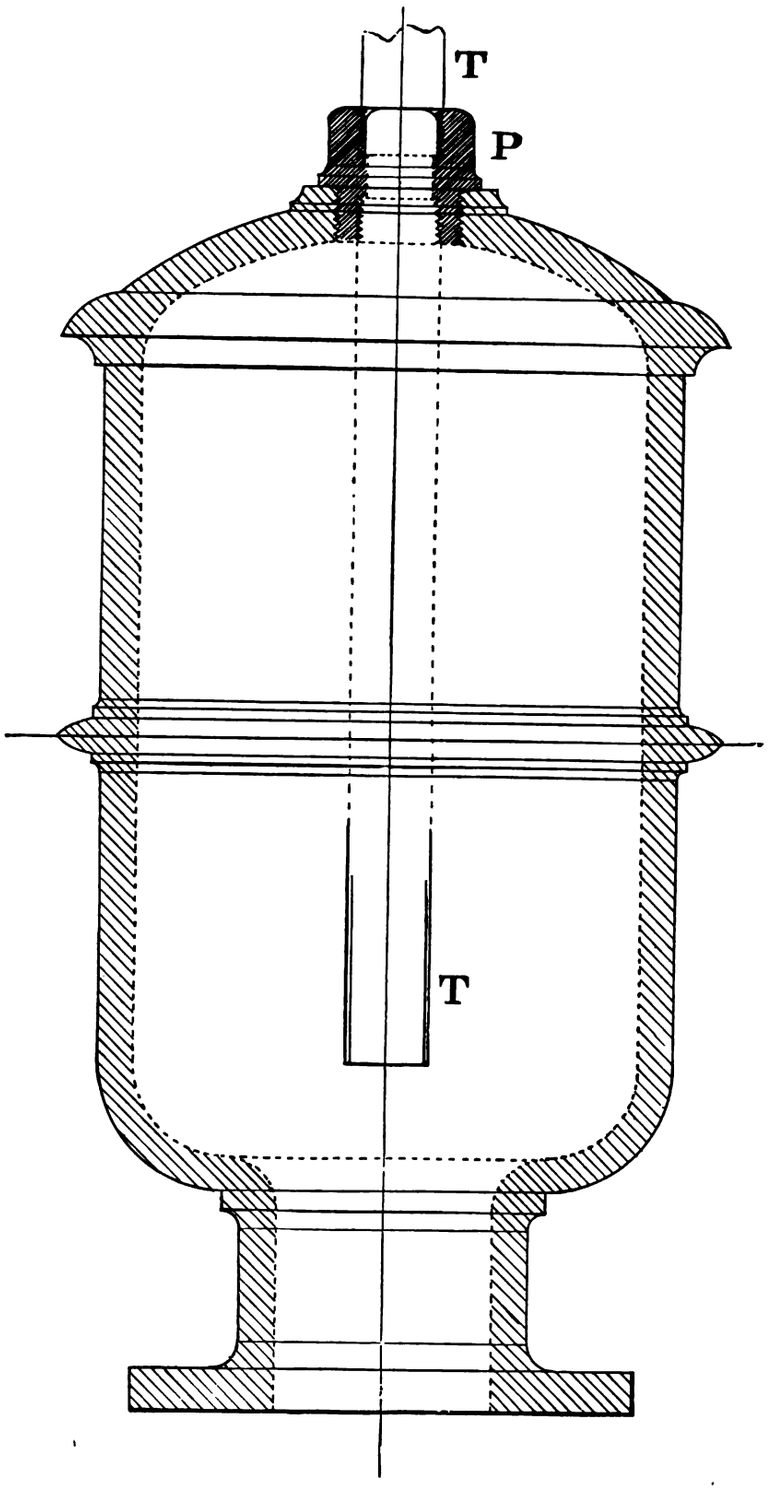

FIG. 9.

process is sometimes shown, by making a broken line representing the fracture; but in such cases as this, it would merely be hideous without any compensating advantage.

EXAMPLE IX.

21. A vertical shaft, Fig. 10, upon which is pinned a collar *C*, supporting a piece *B* which turns freely on the shaft.

This again illustrates the advantage sometimes gained by sectioning over an outside view. Both *B* and *C* are of such form that outside views of them are needed, or at least best suited to the circumstances. But an outside view *only* of these three pieces in place would be ambiguous, since it would appear exactly the same were *B* and *C* made in one piece. This ambiguity is entirely removed by sectioning over the outlines, which nevertheless explain the outward forms just as clearly as if it were not done.

A very common but very objectionable practice in such cases as this is to make an end view also, showing all the pieces in place: with the result of showing nothing clearly. The only reasonable method is to make an end view of each piece by itself, as in the figure: though in the case of the collar, *C*, it may be rather an advantage than otherwise to show the shaft within it, if, as is here done, it be drawn in section.

And in general, it is to be recollected, the fact that in one view a number of parts are shown as put together is not a sufficient, and often is not even a good, reason for preserving that arrangement in other views,—*in which they should be separated if that shows them more clearly.*

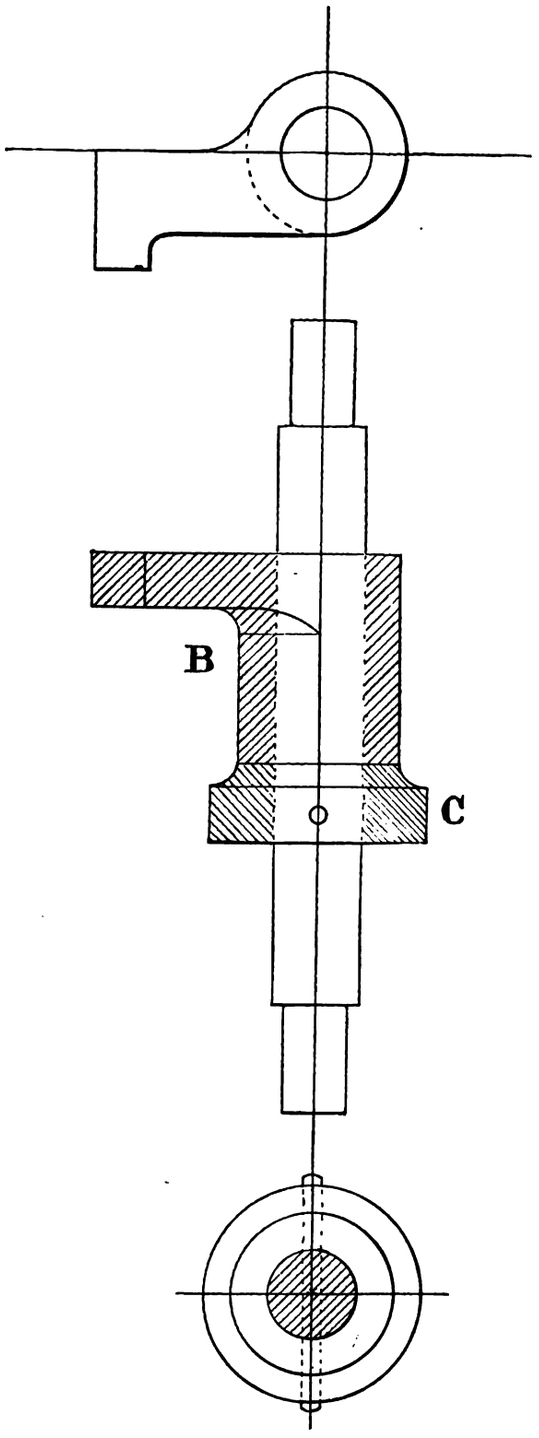

FIG. 10.

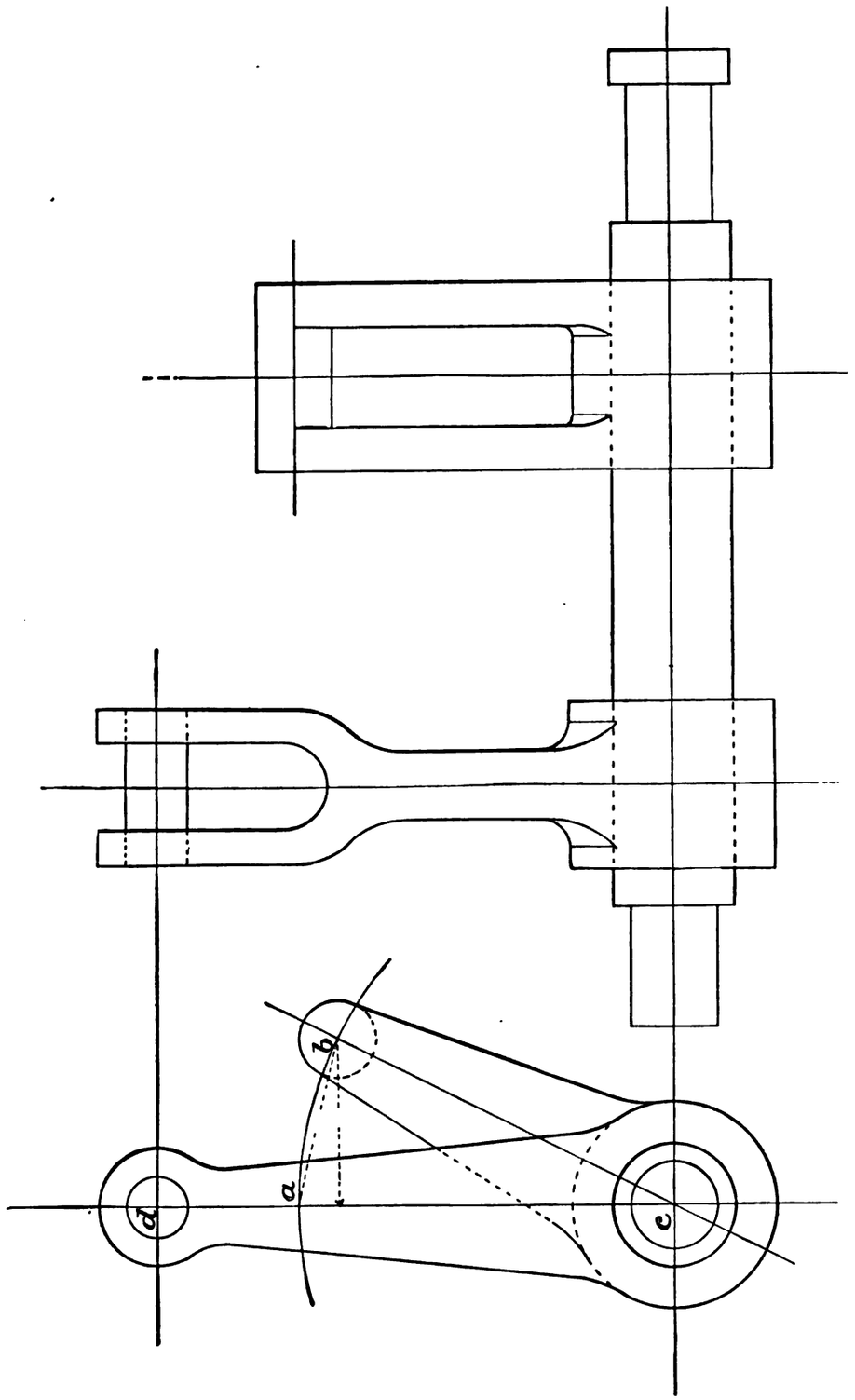

FIG. 11.

EXAMPLE X.

22. A rock-shaft, with two levers which are not in line with each other, is shown in Fig. 11.

This combination differs from the preceding in the particular, that no confusion is caused by superposition of lines in the end view, although the parts are there shown as put together; which indeed is necessary in order to define the relative position of the two levers.

This is best done, as shown, by placing one of them so that its centre line is vertical, as *cd*; the side view of that one will then correspond to it as a true projection. The centre line of the other lever is drawn in the end view at the correct angle with that of the first; which angle is best defined on the drawing by describing an arc, *ab*, through the centre of the second pin, about *c*, the axis of the rock-shaft, and marking in figures either the length of the chord *ab*, or else the *offset*, or horizontal distance of *b* from *cd*, or both.

But in the side view the formation of this second lever is best shown, not by projecting it in its inclined position, but by drawing it as though it also were vertical. *Thus the true dimensions are seen in both views;* which is essentially more explanatory than it is to exhibit the same relative position of parts in both views, whenever, as is the case here, some parts would thereby be foreshortened.

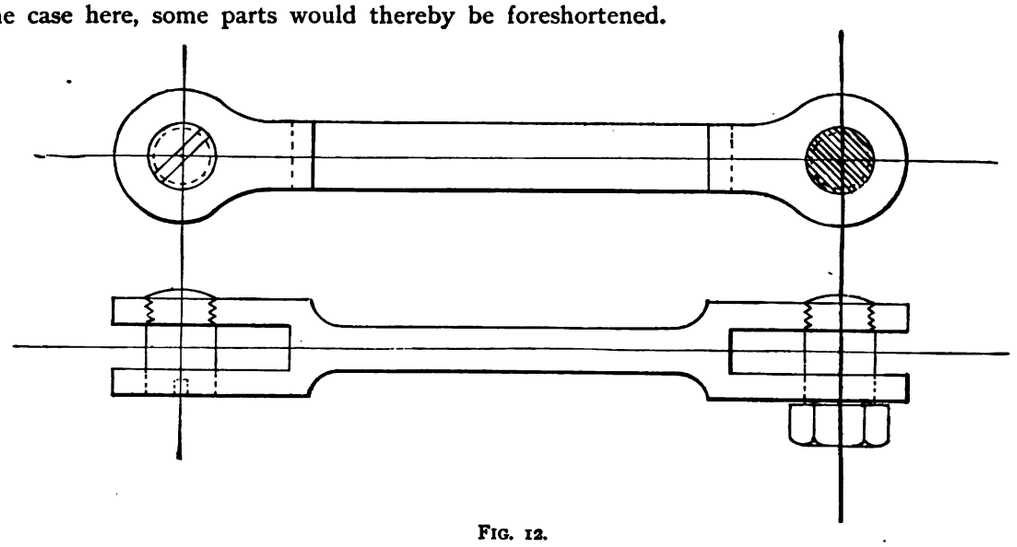

FIG. 12.

EXAMPLE XI.

23. A simple link with a jaw at each end, Fig. 12. The pin at one end is slotted for a screw-driver, that at the other end being a tap-bolt.

The tap-bolt being intended solely to serve the purpose of a pin, must neither bind the jaw nor be liable to work loose. Its head must therefore not touch the outside of the jaw, and accordingly, in the side view, it is limited by a line *just far enough from the jaw to show daylight between them.* And that it may stay in place, the thread *bottoms*, just as in the case of a standing bolt; as shown by the abrupt termination

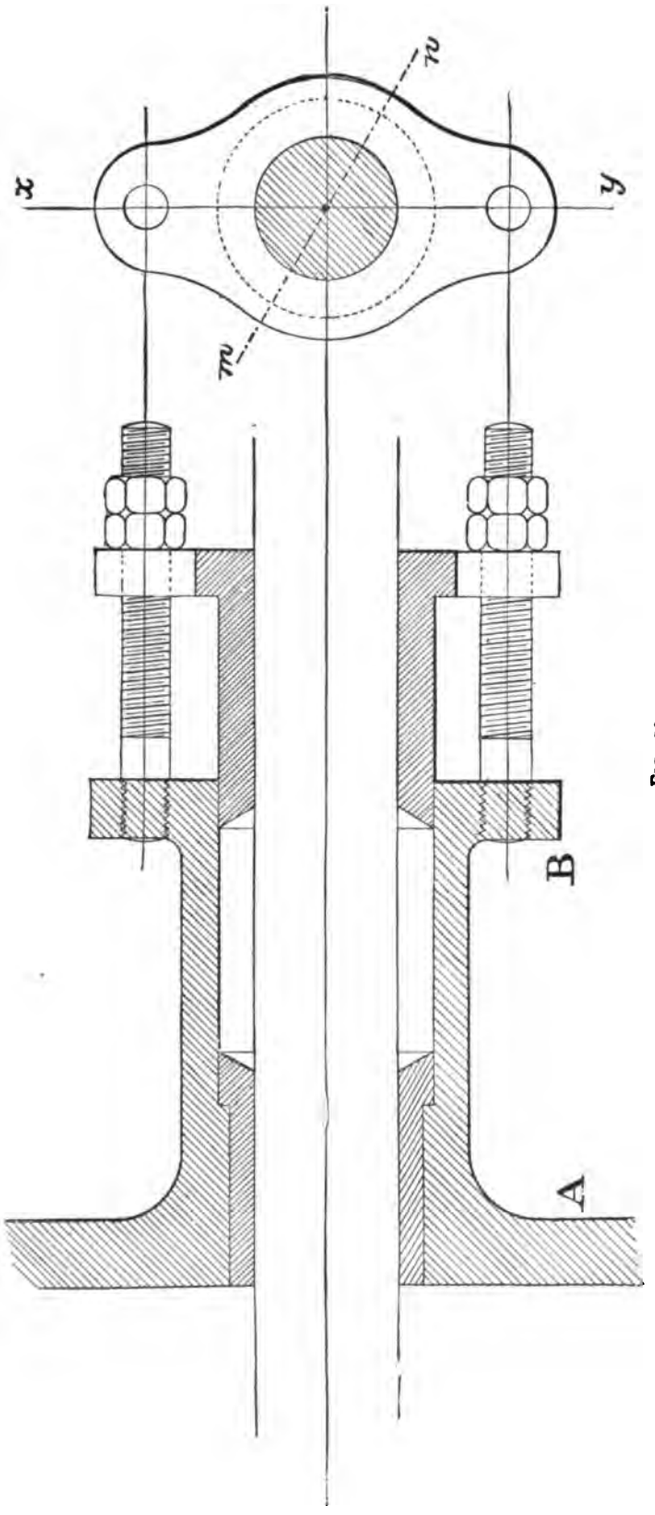

FIG. 13.

of the thread at the face of the jaw. The hexagonal form of the head being fully shown in the side view, the pin is best shown in the other view in section, as though cut off flush with the jaw.

The other pin also must be screwed in till the thread bottoms: in the side view the true size of the slot is shown; that is to say, the slot is supposed to be *perpendicular to the paper*, as it always should be, for the simple reason that it thus shows more clearly what is intended. In the other view it should be placed in whatever position will make it most conspicuous. Just what that position is, may depend upon circumstances; if possible to avoid it, the sides of the slot should not be parallel to either centre line,—and in this case they are drawn at an angle of 45° to each.

EXAMPLE XII.

24. A stuffing-box, with gland and bolts, Fig. 13. This stuffing-box is cast as part of the cylinder-head *A*, and has a circular flange *B*, in which are fixed two standing bolts, which pass through lugs formed on the gland.

This drawing is made on principles in direct opposition to those of strict projection. In the first place, the cylinder-head and the stuffing-box itself are shown in complete section, the standing bolts being drawn as in Ex. I.

Now, if a true section were made by the plane *xy* through the gland, (which is

too often perpetrated,) no one could tell, by looking at that section, but that the gland itself had a large circular flange, as well as the stuffing-box, which might very easily be, and often is, the case. But here, the gland is furnished only with two lugs, which toward the centre spread out and merge into a stiffening ring, or narrow flange, formed at the outer end of the gland.

That this may be distinctly kept in view even while examining the sectional drawing, the lug is there shown in elevation, while the body of the gland is shown as though a section by the plane *mn* were turned about the axis into the plane of the paper.

And it should be shown in the same way exactly, whether the bolts are actually on the vertical line or not; the required position of the gland being shown in the end view.

EXAMPLE XIII.

25. A valve and valve-seat for a water-pump, Fig. 14. The valve consists of an india-rubber disk into which is sprung a central eyelet of brass, bored out to slide freely on a sleeve which supports the valve-guard that limits the lift of the valve; the whole being held in place by a bolt passing through the sleeve and guard, and also through the central hub of the seat.

We have here another case in which the sectional view is constructed, not to exhibit a knowledge of projections, but to convey information by any means which will do it clearly.

The valve-seat is a grating, circular in outline and having a central hub from which arms radiate, as shown in the top view, where everything relating to the thickness and arrangement of the arms, the form and dimensions of the openings, etc., is made evident at a glance.

A second glance makes it equally evident that the regular proceeding dictated by the laws of projection, that is by making a vertical section through the plane *xy*, would make the other view very unsatisfactory and actually misleading: nor in fact is there any one plane which can be so passed as to render a true section by it very explanatory.

Accordingly, the sectional view is constructed as follows: the bolt is first drawn with the flat side of the square head parallel to the paper; the exterior lines of the hub are then drawn, so as to show its true diameter, next the inside and outside lines of the central ring of the grating, in which the inner arms terminate, then the inside line of the outer ring; thus the outer part only of this view is a "correct" section, such as is insisted on by extreme advocates of order and system. But *it tells its story*, and tells it more truly than it can be told by calvinistic observance of the letter of the law. The end justifies the means.

It is so obvious from these two views that the rubber valve is round, and also the eyelet and the sleeve, that it would be ridiculous to make end views of those pieces in a working drawing. A top view of the guard would be necessary—which is not here given, as the object of the illustration is simply to call attention to the manner in which the sectional view is constructed.

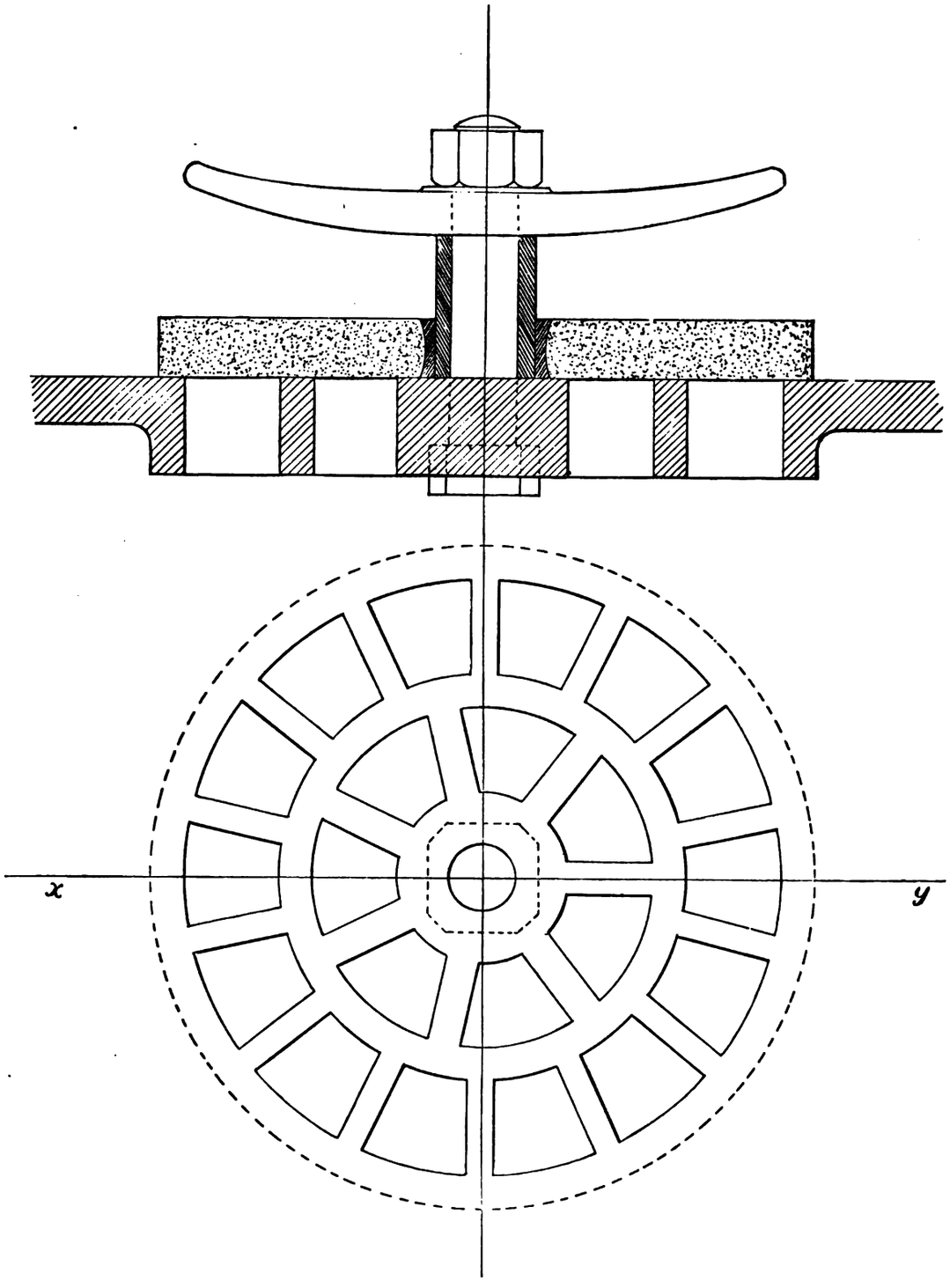

FIG. 14.

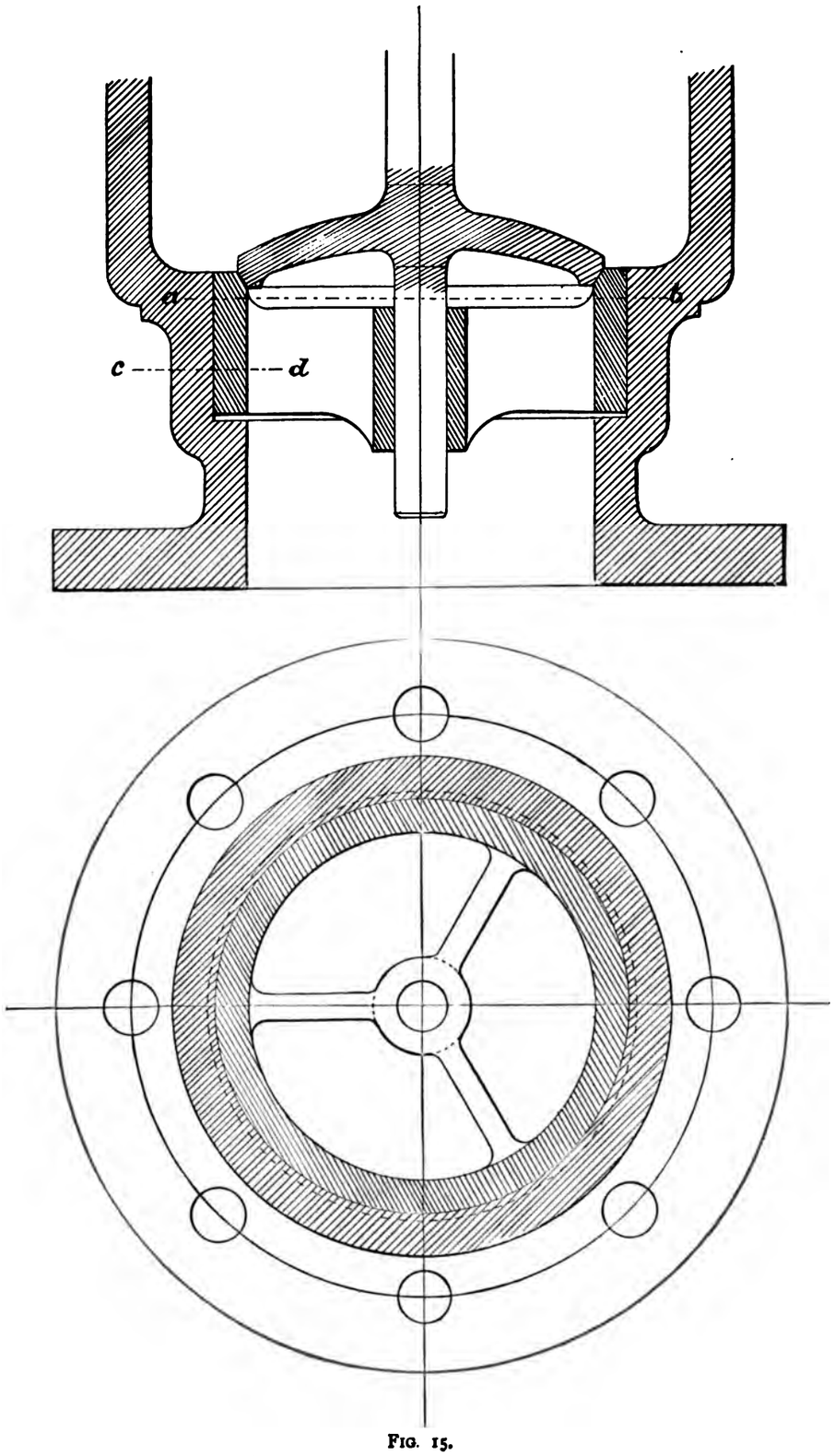

FIG. 15.

EXAMPLE XIV.

26. Fig. 15. A poppet valve and valve-seat.

The valve, supposed to be of brass, is made of a dished form for strength, and cast in one piece with the stem, the lower part of which serves as a guide to insure correct seating when the valve closes. Large fillets are shown at the junction of the valve with the stem both above and below: and as the stem is best shown in outside view, thus indicating its cylindrical form by the absence of shadow lines, the fillet lines are drawn in. The body of the valve is shown in section, and the cross-hatching is continued a little way upon the stem, merely terminating indefinitely without a line of fracture being shown.

The valve-seat, also of brass, consists of a cylindrical, or rather very slightly tapering ring, tightly driven into the neck of the cast-iron valve-chamber. Within the ring, and forming one piece with it, is a spider of several arms, supporting a central hub through which the lower part of the valve-stem slides freely as a guide. This seat is also shown in section, the two sides being drawn as symmetrical, an outside view of one arm of the spider being made on each side of the centre line, without regard to the actual number or position of these arms. These particulars are defined in the top view, in which the valve-seat is shown as cut by the horizontal plane *ab*. But this plane is not extended to cut the metal of the valve-chamber; for a much clearer idea of the general proportions is given by cutting the cast-iron neck by the plane *cd*. In a shop drawing it would not be obligatory to make this top view at all, since it would practically suffice to write upon the longitudinal section the instructions about the spider, thus: "Three arms, $\frac{5}{8}''$ thick," and also the number of bolts in the lower flange of the chamber.

EXAMPLE XV.

27. Drawing of Spur-Wheels. Fig. 16.

A spur-wheel if very small may be made by cutting teeth in a simple disk of metal, as in the change-wheels of engine lathes. But large wheels usually consist of an outer rim on which the teeth are cut, connected to the central hub by arms or a web. In general structure then they closely resemble the pulley and the hand-wheel, illustrated in Examples IV and V; like them they are best represented by an end view and a longitudinal section, and, as explained in relation to them, this section should be made so as of itself to convey the impression of symmetry.

In order to this, the rim should always be shown as if cut between two teeth, and the hub as if cut between two arms, if there be any, as in the figure, without regard to the number or relative positions, which are shown in the end view. In the larger of the wheels in Fig. 16, the hub has an external flange, and the rim an internal one; to which the ribs of the arms are joined by fillets. The section at *b b* shows the form of the arm, as in Fig. 6, and thus the structure of the whole is fully defined.

If time presses, it is quite permissible in a shop drawing to draw only a few of

the teeth, as in the figure; this defines the contour, and for the rest it is sufficient to draw the pitch circle and the outline of the blank, and to mark in figures the number of teeth required.

28. The smaller wheel is introduced for the purpose of showing how two wheels in gear with each other are best represented in section. If cut by a single plane, which

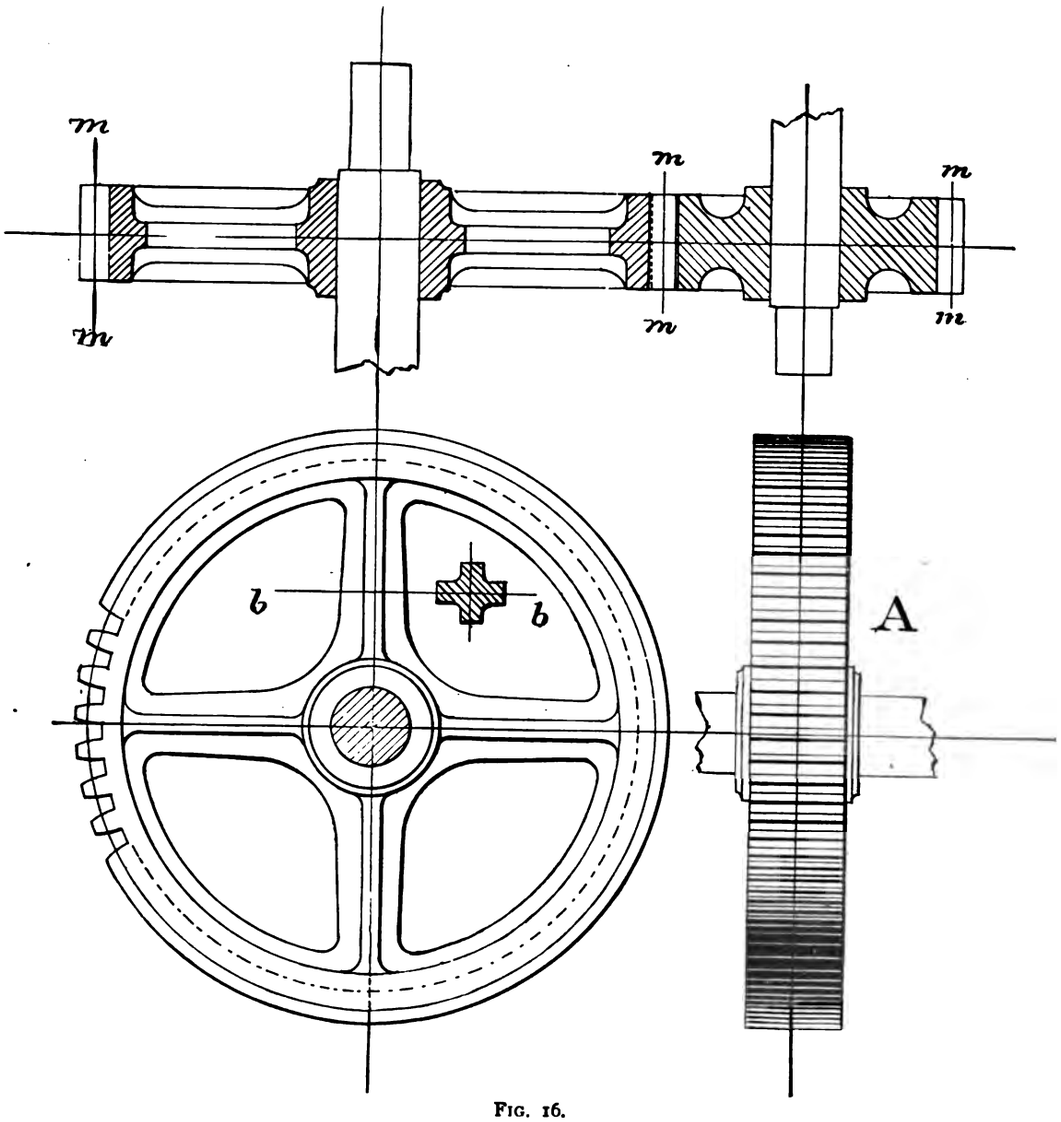

FIG. 16.

would pass through a tooth of one and a space of the other, the effect is indistinct and misleading. Instead of this, each is cut through a space, and the tooth of one is thus placed in front of a tooth of the other; the top of this latter tooth is therefore dotted, but the bottom of the space is shown in a full line, thus making the clearance obvious at a glance; and the junction of face and flank is indicated by drawing the hair lines *m m*, which are the outlines of the pitch cylinders.

The side view of a spur-wheel in elevation is very seldom introduced in a detail drawing, as the longitudinal section usually answers every purpose as well if not better, and is in any case necessary in addition to the outside view if the latter be made for any reason. Still it is occasionally desirable, and in a general drawing it may be necessary: so that a few words in regard to it are appropriate.

And it is to be stated, that there is no one thing, unless it be a small screw, in which the labor of making a correct projection is so absolutely thrown away as in such an outside view of a spur-wheel.

It is utterly ineffective, and it is hardly too much to say that the more accurate it is, the less will it look like a wheel; it will convey no impression of roundness, and very little of the existence even, let alone the forms, of the teeth. This last, indeed, is of little account, but the drawing, to be of any practical use, must at least look round and give an idea that there *are* teeth.

29. The manner in which this may be effected is shown at *A* in the figure. Beginning at the side from which the light is supposed to come, lines are drawn parallel to the axis, at first as if for shading a cylinder as large as the blank: when this has been carried a small distance, the tops of the teeth are indicated by drawing a double line for each, the line away from the light being made a shadow line. The breadth of the tops, and the spaces between them, are slightly increased as they approach the centre line, and again gradually diminished as they recede from it toward the position of the line of shade upon the cylinder of the blank, beyond which it is useless to continue the indication of the tops of the teeth, unless for a very little distance; and the remainder is finished as though merely shading the cylinder. Some practice, and good judgment, are required to produce the most satisfactory effect in any given case, as the treatment must vary in detail according to the size of the teeth as well as the size of the wheel.

It is to be understood that this operation is not for the purpose of *representing* the wheel, in the sense in which that word is used in general, and particularly in treating of projections. No attempt is made to make the lines indicating the tops of the teeth agree in number or position with the contours shown in the end view; and the whole is to be explicitly considered as an *indication* only, and not in any sense a drawing, of the wheel.

If occasion arises to show the side view of two wheels in gear in this manner, a slight modification is necessary, since the cylinders of the blanks are not tangent to each other; on this account, the above-described shading of that one whose engaging side is toward the light should begin at a distance from the axis equal to the radius of the *pitch circle*. This wheel should be first completed, and the other one afterward treated in the same manner: by which the encroachment of one upon the other due to the meshing of the teeth will be indicated in a manner which will make it intelligible without reference to the other view.

EXAMPLE XVI.

30. Drawing of Bevel Wheels. Fig. 17.

The sectional view shows two bevel wheels in gear, the smaller one cut out of the solid, the larger one of sufficient size to require the web, which connects the rim with the hub, to be stiffened by ribs. If the wheel were larger, the connection would be by means of arms—in regard to the drawing of which the same methods would be followed as in the case of spur-wheels and pulleys.

The form of the tooth is in this case shown, not in the end view of the wheel, where it would appear foreshortened, but by making a drawing by itself of each end of the tooth, as *m*, *n*. This being done, the section itself would suffice for a working drawing if the wheel be solid or have a web only: and on a pinch it would answer when, as in this case, ribs are added, if definite instructions be noted on the section, as for example "Four radial ribs, $\frac{1}{8}''$ thick;" for the shape of the rib is defined in the sectional view.

If arms are used, an end view is necessary, and the section of an arm should also be given as in Figs. 6 and 16. In no case is it *necessary* in the end view to show the teeth, a drawing of the blank only being required in order to make the wheel: but of course the work looks more complete if the teeth be drawn.

In making the section, the rim should be cut between two teeth; and the hub between two arms or ribs, as the case may be, as previously explained. And in this sectional view *the pitch cones should always be shown*, being drawn like the centre lines, either hair-lines if in black, or a very little heavier if in red ink or other distinguishing color.

31. In a working drawing, it is not advisable to draw the inner ends of the teeth, which are actually visible on the farther half of the wheel; for they would be foreshortened, and what is of more consequence, would rather diminish than increase the clearness of the drawing: in a general plan it may, however, be desirable thus to complete a wheel which may be shown in section, particularly if other objects beyond are partially concealed by it.

In regard to a side *elevation* of a bevel wheel, it is to be noted that since the forms of the teeth are actually shown, although foreshortened, a true projection not only does convey a correct impression, but nothing else will: with this mitigation, however, of the labor of making it, that it is not necessary to be rigidly precise in determining the contours of the ends of the teeth.

The preceding remark, it is to be understood, relates to the *representation* of the wheel in outside view. In many cases an *indication* will suffice, which is much less difficult to make, consisting of the frustum of the pitch cone, limited at the outer end by that of the normal cone, as shown at *A*. But this is open to the objection, which in particular cases may have some weight, that it is an exact representation of conical friction gearing.

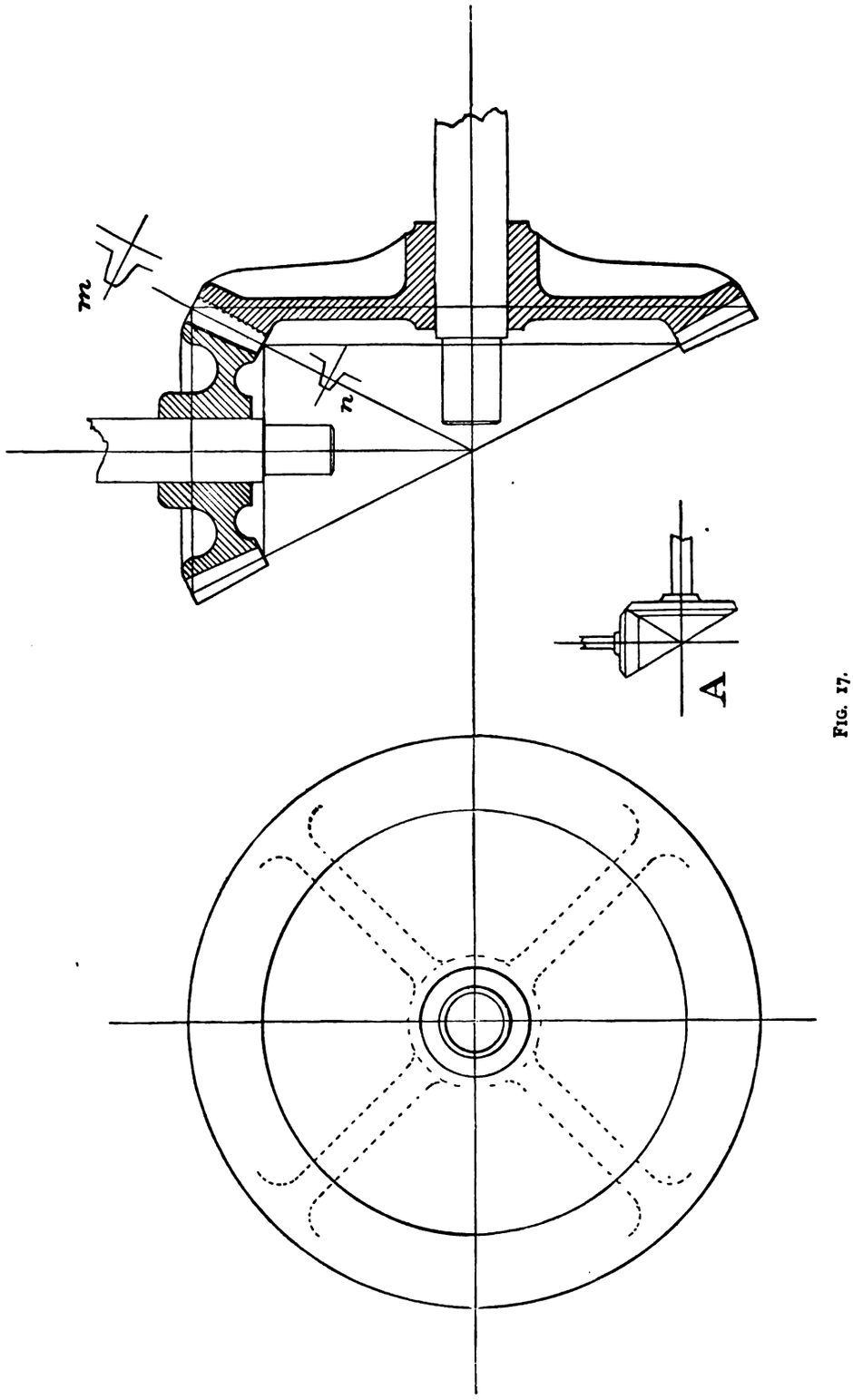

FIG. 17.

EXAMPLE XVII.

32. Drawing of a worm and wheel. Fig. 18.

A worm-wheel, like a spur-wheel, is cut out of the solid if small, and if larger has arms or a web to connect the rim and the hub: and its longitudinal section is accordingly drawn in a similar manner, the rim being always cut between two teeth and the hub between two arms.

But in making the section of the rim, we have here a new state of affairs owing to the twist of the teeth: a plane through the axis would cut the teeth obliquely, making a very confusing representation. Consequently the drawing is made just as though the rim were sawn across along a line drawn in the middle of the space, making a twisting cut.

In connection with this section of the wheel, an end view of the screw is given, the correct distance between the centre lines being laid down as when in gear, as shown on the right in the figure. The screw is not shown in section in this view, but the spindle may be cut off in front of the screw, as shown; the engaging tooth of the wheel being thus concealed, is dotted in.

An end view of the wheel is of course needed; but in a working drawing this may in the main be a drawing of the blank, the required number of teeth being marked in figures, and the teeth themselves being shown only so far as to include those which engage with the screw, and one or two more on each side. In showing these teeth, the preferable method is to make a section of the rim by the plane xy, drawing in the contours of the teeth as thus determined, and also the parts of them which lie beyond the plane of section: these last should be true projections, but if there be a central web, it should not be shown as cut, and indeed even when there are arms, it is as well to show the inside line of the rim in full, and draw the arms as though they were beyond the cutting plane.

33. The side view of the screw should be a true projection and accurately drawn. This will of course hide a part of some of the sectioned teeth; and in order to give fuller and more exact information, there should also be given, as at A, a section of the screw, in which the pitch line of the rack thus formed is drawn, and the central section of the wheel should be repeated, drawing it as in gear with that rack; with an arc of its pitch circle also.

The above suffices for a shop drawing from which the worm gear is to be made. In a general plan, it will often suffice to make the side view of the wheel in section; but hardly so with the end view, and in many cases it is necessary to show both views in elevation.

Then there is nothing for it but to face the guns and carry the battery: as in the case of the bevel wheels, a drawing in projection is necessary to convey any reasonably good idea, if the scale be not very small: though as no measurements are to be taken from it, extreme precision in constructing the curves is not essential. On a very small scale, it may be admissible to make a mere indication by drawing

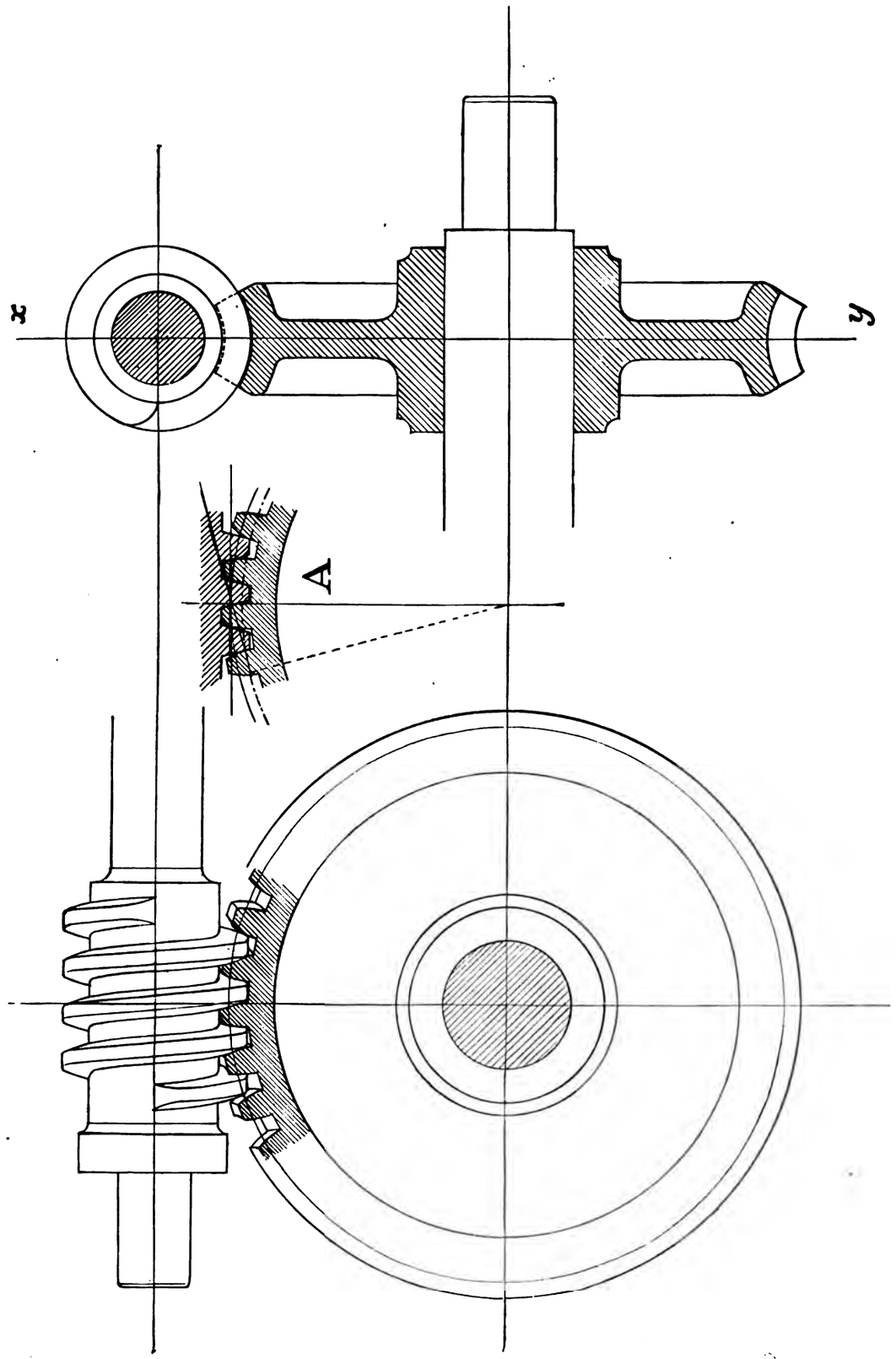

FIG. 18.

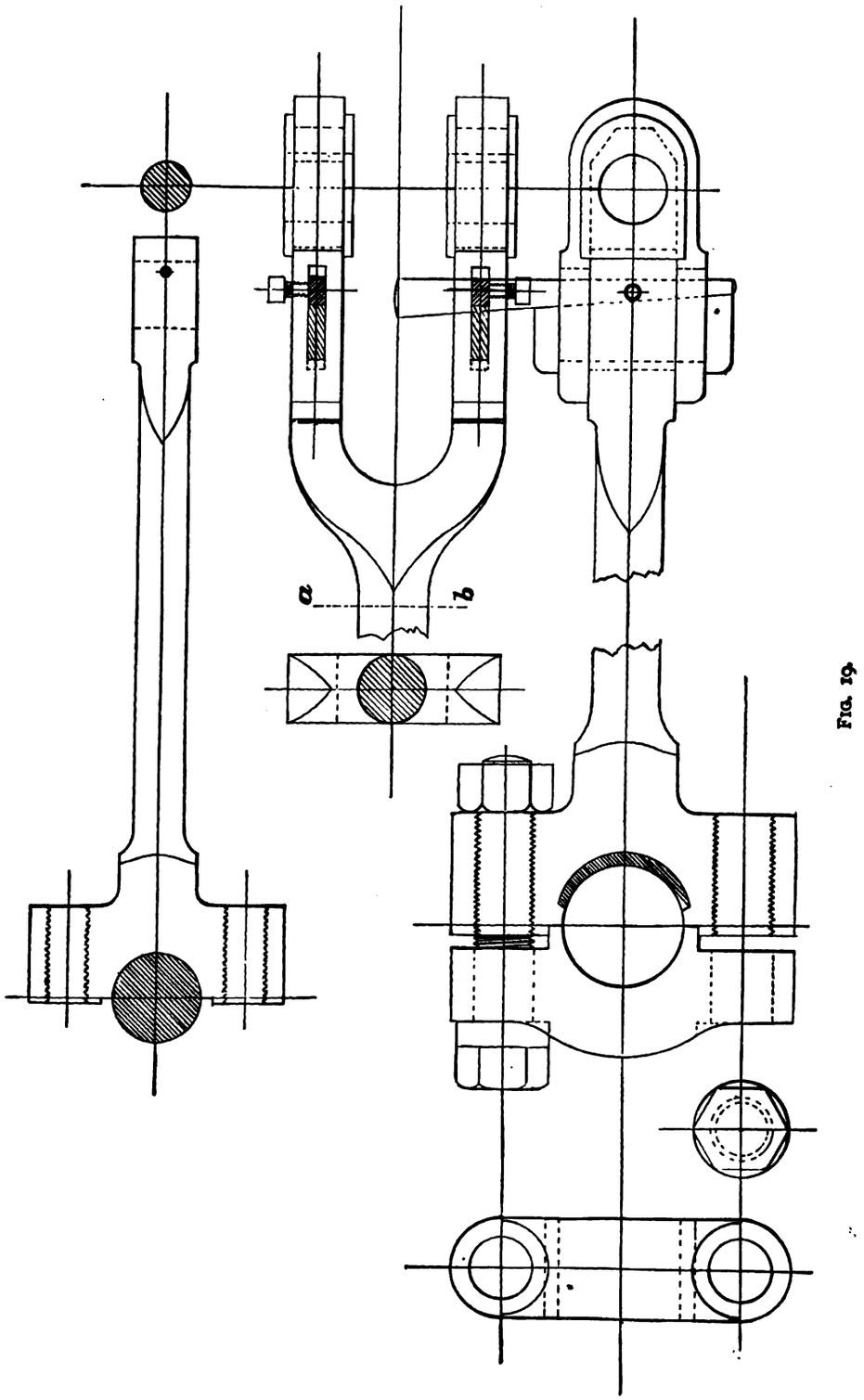

FIG. 19.

the pitch cylinders only, with lines for the helical teeth: but this is a very unsatisfactory makeshift.

EXAMPLE XVIII.

34. A connecting-rod, with one "pillow-block" end; the other end is forked, and each arm of the fork terminates in a "strap and end." Fig. 19.

This drawing illustrates mainly the selection and arrangement of the views needed for the use of the workman. It needs no reflection to perceive that a top view of the pillow-block end would be of no use whatever; all the information not contained in the front view is conveyed by the end view of the cap, which being *from* the left, is placed *at* the left, and in it the bolts are not drawn, their whole construction being fully explained in fact by the drawing of the upper one in place, in the front view: still the detached end view of one is added, as it adds almost nothing to the labor.

In regard to the forked end, a front view is just as important as in the case of the pillow-block end; but here an end view would be very obscure and of no assistance in reading the drawing or in making the rod, which absolutely requires a top view. The peculiar finish of the fork, however, where it joins the round shank, is better explained by a section through *ab*, looking from the left toward the right, which is accordingly added.

35. Such drawings of the *ends* of connecting-rods should be made full size, or on as large a scale as convenient; but it is not at all necessary to place the centres at the full distance apart: still, a drawing of the shank being requisite, of its full length and in true proportion, this is made on a smaller scale as shown above; the circles for the pins are drawn, upon whatever scale may be admissible, at the correct distance apart: the two ends of the shank are then reduced to the same scale, placed in their proper relations to these circles, and the contour of the shank is completed, all the paraphernalia of caps, straps, brasses, etc., being omitted. If the shank be turned, as is very commonly the case, only one view is needed: which of course should be drawn upon the same sheet with the details of the ends.

EXAMPLE XIX.

36. In Fig. 20 is shown a part of a combination, similar to the "Horton Lathe Chuck," but in this case having its axis vertical when set up in place.

This casting is formed with ribs on the upper side, and facing strips on the lower, the arrangement of which cannot be clearly shown without direct views of each side.

When there is nothing to the contrary, it is no doubt a good idea to represent an object in even a detail drawing, in the same position as in the general plan. Now there are many who think there never is anything to prevent this; and in such a case as the present, it is not unusual to find the piece thus shown: a view from above is of course given, and easily read; — but there will also be given a "view from below," or, as it is frequently labelled, a "bottom plan;" which is *not* easily

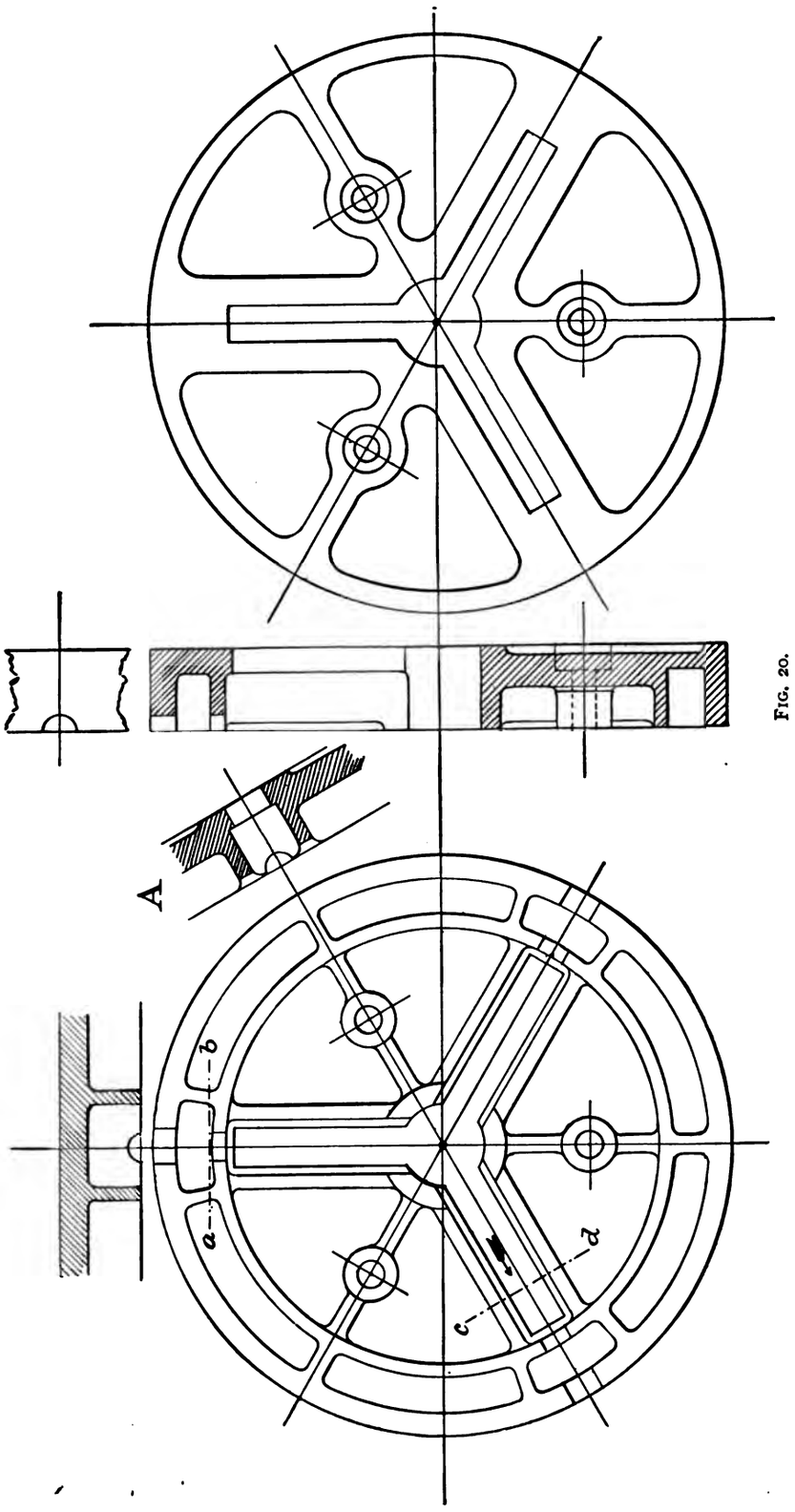

FIG. 20.

read, for the simple reason that it is seen from an unusual direction. In examining a detached piece of any machine, it is perfectly natural to look down upon it from above, especially if the piece has a horizontal position when in place: but nobody ever gets under it and looks upward, in order to ascertain what is there, if he can help it. This ought to be kept in mind in making the drawing; the draughtsman does not stand on his own head, and he should not ask other people to stand on theirs. The top view is, naturally and correctly, placed over the side view; and the difficulty is sometimes gotten over by making a new side view in which the piece is inverted, and drawing another top view over that. This is decidedly better than to place it under the first side view and label it as above mentioned, but still it is not always very easy to realize the correct relations between the upper and lower parts when drawings are thus arranged.

37. The advisable expedient is to place the piece on its side and draw it in that position; then a view of the parts on the left placed at the left, and a view of those on the right placed at the right, of the view first made, will be readily understood. Just as though the drawing first mentioned were the south front of a house, and the other two the west and east fronts respectively. And that is the course here adopted: the axis is placed in a horizontal position, and the central view is a section made in accordance with the principles illustrated in Figs. 21 and 22.

Over this is placed an outside view of a small portion of the upper part, in order to define clearly the semicircular groove in the outer flange on the left side of the casting. Above the view at the left is given so much of a section by the plane *ab*; looking downward, as is necessary to explain the relation of the small radial ribs thus cut, to the surrounding parts; and this also shows the semicircular groove in the inner flange.

This groove is also seen in the section at *A*, which is made by the plane *cd*, and seen from the direction indicated by the arrow. It may be said that this section could have been put nearer to its plane by drawing it on the other side of the large view—which is true; but if that were done the arrow ought to be reversed and the section looked at in the opposite direction, which would not be so clear nor so explanatory.

EXAMPLE XX.

38. Fig. 21 exhibits the Slide-valve, Valve-chest, Valve-seat and a part of the Cylinder of a horizontal steam-engine.

This example illustrates the advantage of selecting cutting planes in such a way as to show clearly what is desired; using in the same view as many different planes as may be found necessary or convenient.

The longitudinal section of the cylinder and valve-chest is by the plane *ab*; but that of the valve is by the plane *cd*, which evidently shows its structure more clearly.

In the top view, the valve-chest is cut by a horizontal plane through the centre of the valve-stem and steam-pipe. But the valve and stem, and the stuffing-box, as well as the bolts, are omitted. The bolts pass through half-sleeves cast on the outside

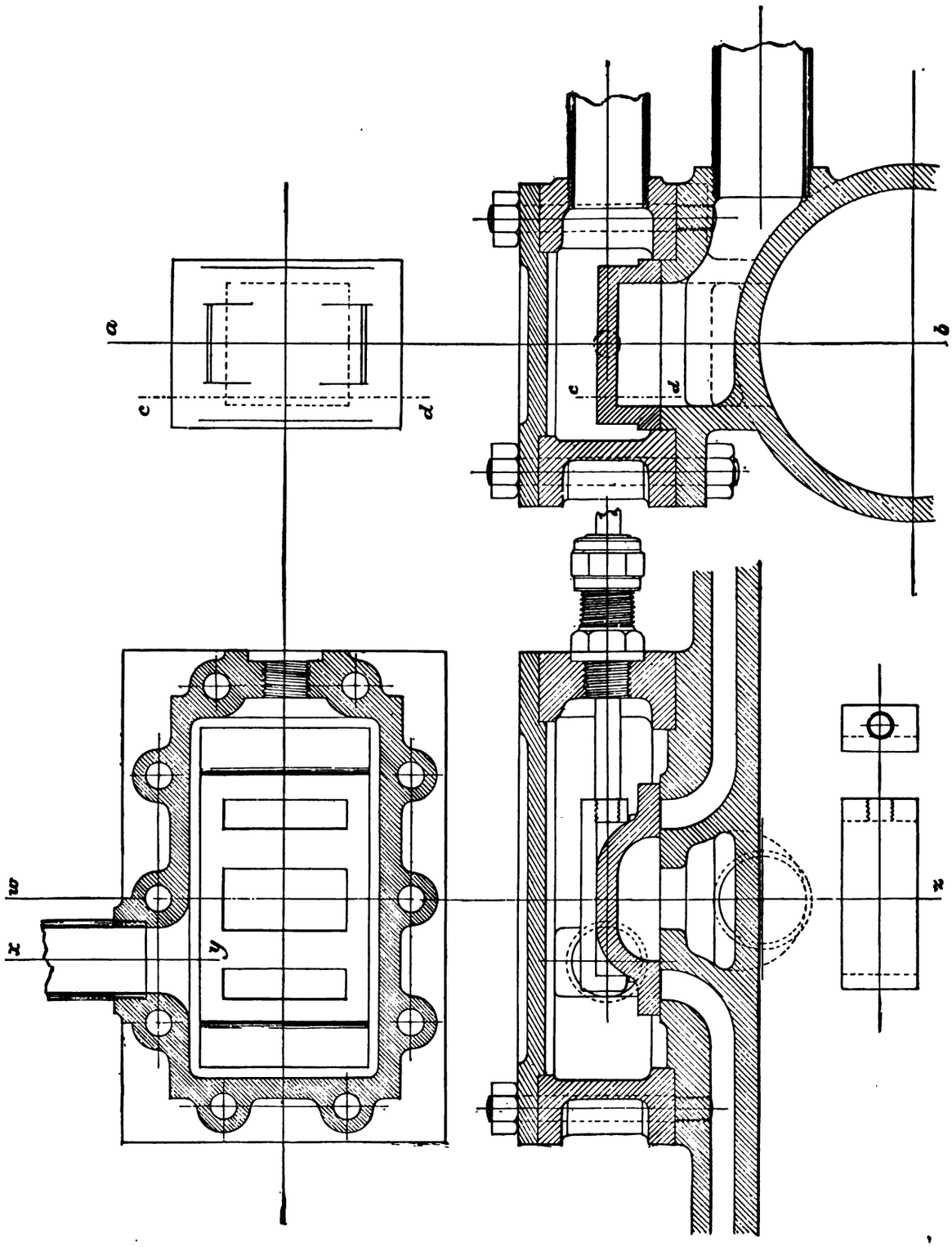

FIG. 21.

of the wall of the chest, and this drawing is much clearer than it would be if the bolts were shown in section.

The relation of the chest to the valve-seat is made more distinct by omitting the valve (of which a detached top view is given over the transverse section), and showing the seat with its ports. But this last would of course be repeated in the drawing of the cylinder, (in which the valve-chest would be removed,) exhibiting the hubs which must be provided for the standing bolts at the end of the chest, as well as the exhaust opening. These last items are therefore omitted in this drawing, the seat alone being all that is needed in connection with the valve and chest.

39. In the transverse section, the cylinder and valve are cut by the plane *ws* through the centre of the exhaust port and pipe. But this plane, obviously, would cut the valve-chest in a very unsatisfactory manner, for it passes through the axes of the two central bolts. Therefore, the plane *xy* through the centre of the steam-pipe is chosen instead. Nevertheless, the middle bolt on the right-hand side is dotted in; for it must somehow and somewhere be shown that a standing bolt must be used in this position also; and it can be shown nowhere else so well as here. Nor does this in the least confuse the drawing, for the outline of this bolt coincides exactly with that of one beyond the cutting plane. The plane *xy*, in the present instance, passes between two bolts on the left-hand side of the steam-chest, which is therefore shown as also cut by this plane in the transverse section, so that the main wall of the chest is shown in its true relation to its flanges, the half-sleeve surrounding the bolt beyond is shown in outside view, and the bolt itself is dotted in.

Thus in each of the two lower sections, two different cutting planes are employed; and had a bolt chanced to lie opposite the steam-pipe, there would have been no hesitation in cutting the left-hand side of the chest by a third transverse plane which should *not* pass through the axis of that bolt.

The advantage in respect to compactness, by adopting the methods here explained, is self-evident, as all the sections made use of are necessary. Nor is there a point left in doubt, with the single exception of the arrangement of the interior of the stuffing-box; in a plan on a practical scale, this would be dotted in, and made distinct by sectioning over the outlines, as in Figs. 27 and 28.

40. It is not pretended that the above examples include all the infractions of the laws of projection, or departures from the methods of descriptive geometry, which may be found useful. But though it is hoped that they include a sufficient number to be of practical service, the writer still more strongly desires that they may prove suggestive of others, and that the reader, freeing himself from the trammels of precedent and prejudice, may make rapid progress toward the highest efficiency: which it is as vain to expect of the rigid formalist, as it is to look for the healthy growth and full development of a bark-bound tree.

CHAPTER II.

ON THE REPRESENTATION OF BOLTS, NUTS, SCREWS, AND RIVETS.

1. In every working drawing, it is essential that the fastenings, such as bolts, screws, and rivets, should be as clearly indicated as any other detail.

But it does not follow that they need be drawn with the same degree of precision. For in every machine-shop a system of some kind is adopted, in which the diameter of a bolt determines the number of threads per inch, as well as the sizes of the head and the nut. So that in respect to these particulars it does not matter whether the drawing be made in exact accordance with the standard or not; and much time may be saved by adopting the following methods of representation:

2. Bolt-heads and nuts are usually either square or hexagonal; and it is clearly a convenience, in making the wrenches, to have the side of the square, and the breadth or "short diameter" of the hexagon, of sizes that can be readily set off by the scales in common use. Consequently in the case of the hexagon, the "long diameter," or distance from corner to corner, will involve an awkward decimal. This is of no consequence in making the nut, but would be very inconvenient in making the drawing: for the side view of a bolt should *invariably* be such that there is no possibility of doubt or error as to the shape of either the head or the nut; if square the *short* diameter, if hexagonal the *long* diameter, should be parallel to the paper.

3. Calling the diameter of the bolt unity, the proportions given below will be found very convenient in practice, being simple and easily remembered.

Side of Square Nut,	$1\frac{3}{4}$;	Depth,	1.
" " " Head,	$1\frac{1}{2}$;	"	$\frac{3}{4}$.
Long Diam. Hex. Nut,	2;	"	1.
" " " Head,	$1\frac{3}{4}$;	"	$\frac{7}{8}$.

It is only in very massive machinery that bolts used as fastenings are over $1\frac{1}{4}$ inches in diameter: up to that size, the proportions just given do not differ materially from the standards in general use, and the saving of time effected by employing them is sufficient in many cases to be of very considerable importance. Tables for the U. S. and the Whitworth Standard systems may be found in the Appendix.

4. Through Bolts.—Fig. 22 shows two pieces of metal secured together by what is called a *through bolt*, with hexagonal head and nut.

The bearing side of the nut has its corners rounded off, since otherwise the sharp edges and angles would scrape and catch upon any inequalities on the surface against which it bears, thus possibly preventing the bolt from binding: for a contrary reason the corners of the head are not rounded off on the bearing side, though on the other side they may be as a matter of taste in respect to appearance.

Now as to the manner in which this rounding off is represented. The point *b* is first located, either by describing about *c* an arc with radius *cd*, or drawing with the 60° triangle a line through *c* at an angle of 30° with the centre line; then a horizontal through *b* locates the points *a*, *e*, *f*: by trial and error the bow-pen is set to draw an arc through *a* and *b*, tangent to the lower side of the nut, and with this radius the four arcs shown are drawn.

Be it understood that this process does not represent precisely the effect of turning off the end of the nut in the form of part of a sphere, which will be discussed farther on. But it answers perfectly the practical end in view, which is to indicate that the corners are by some means to be prevented from scraping.

The bolt projects very slightly above the top of the nut. This is shown by two vertical

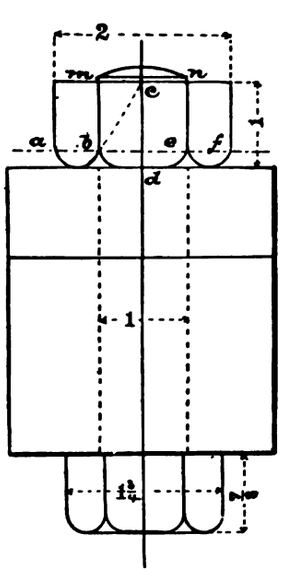

FIG. 22.

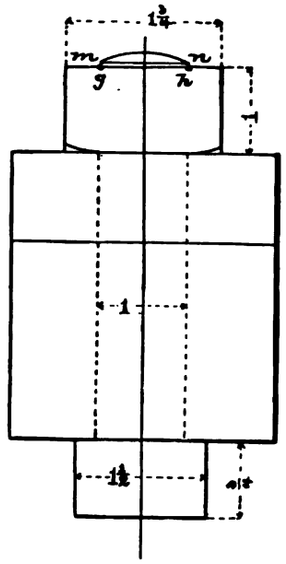

FIG. 23.

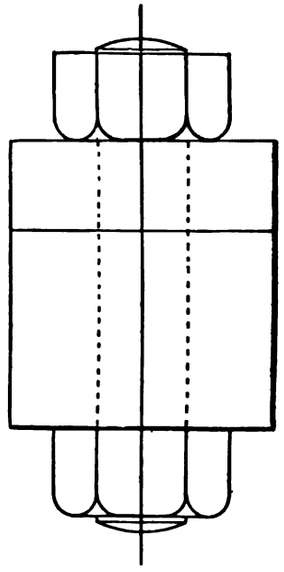

FIG. 24.

lines, just long enough to "show daylight" between the top of the nut and the horizontal line *mn*, no attempt being made to represent the screw-thread: and finally the top of the bolt is finished off by a circular arc about centre *d*.

5. In Fig. 23 we have a through bolt with square head and nut: the corners of the nut are in this case shown as rounded off by two arcs about centres *g* and *h*, with a radius equal to the depth of the nut.

And in Fig. 24 is shown a through bolt with a nut at each end, which is sometimes made necessary by an obstacle that prevents a headed bolt of the requisite length from being put in place.

In this case it is hardly necessary to say that only the nut which is ordinarily to be removed, should have the bearing side rounded off, the other one being reversed, since in unscrewing the upper nut it is rather desirable than otherwise that the lower one should not turn.

6. Tap-bolts.—The *tap-bolt*, Fig. 25, is a bolt with a solid head; it passes through the upper piece, and is screwed into the lower one; the whole bolt being turned by the wrench applied to the head, of which the corners are therefore rounded off on the bearing side.

It is necessary here to indicate the thread, which is done by simply drawing the "Vs" as in making a section of the screw. This is executed by first drawing lightly, in pencil only, two guiding lines on each side, for the tops and bottoms of the threads, making the depth of the thread about $\frac{1}{8}$ the diameter of the bolt; after which the sloping lines are to be drawn at once in ink, using a common steel writing-pen with a fine point. The Vs need not be measured, but are to be drawn free-hand, making a light up-stroke and a heavy down-stroke to represent a shadow-line on the section thus indicated; but it is not material which side of the V is made heavy. This work should be done as regularly and evenly as possible, the angle of the Vs as nearly 60° as may be; and in order to avoid the natural tendency to round the angles, care must be taken to lift the pen entirely off the paper at the end of each stroke.

The thread must extend above the face *rs*, to a distance of, say, $\frac{1}{4}$ the diameter of the

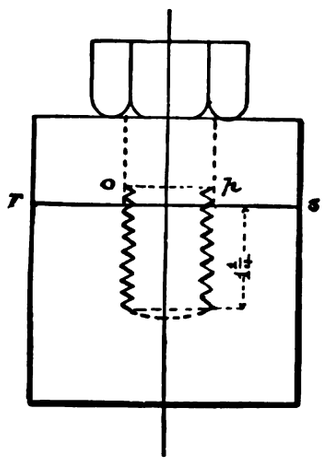

FIG. 25.

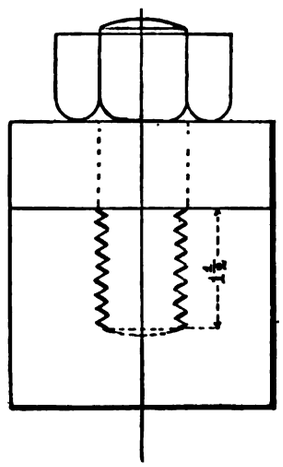

FIG. 26.

bolt, and attention is called to this circumstance by a dotted line *op*: and the lower end of the bolt is finished by a transverse line and a circular arc of radius equal to the diameter.

7. Standing Bolts.—A *standing bolt*, or "stud" as it is sometimes called, is firmly screwed into one of the two pieces to be connected, and remains permanently fixed; the other piece being held down by a nut on the upper end of the bolt, as in Fig. 26. The thread on the lower end is indicated exactly as in the case of the tap-bolt, with this important exception, viz., that this thread of the standing bolt *must terminate exactly at the face* of the lower piece.

This is because it is never intended to come out, and it is therefore screwed in so as to make the thread "bottom" or "jam," thus fixing it so firmly that it will not work loose when the nut is put on or taken off; and the length of this lower thread should when practicable be made equal to $1\frac{1}{2}$ diameters.

8. Key-bolts.—In circumstances which make it undesirable to use either of the fastenings above described, the *key-bolt*, Fig. 27, is sometimes employed.

The thickness of the key should be $\frac{1}{4}$ the diameter of the bolt, its breadth $1\frac{1}{4}$ diameters, and the bolt should extend beyond the key to a distance equal to $\frac{3}{4}$ the diameter. The slot should of course be a trifle larger than the key in each direction; that is to say, "an easy fit" only is required; but it is unnecessary to indicate this by double lines in the drawing: and it makes the construction much more distinct to show the key in section, as in the figure.

The above remarks relate, be it noted, only to the representation of fastenings *in place*, that is, in connection with the pieces which they hold together: and it is proper to call

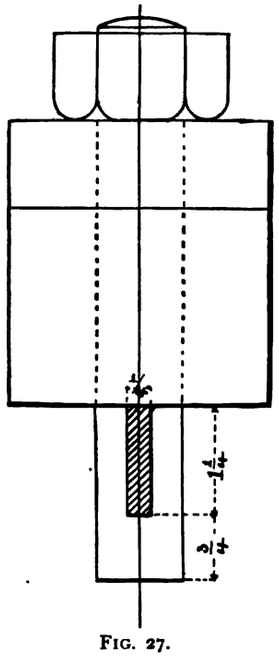

FIG. 27.

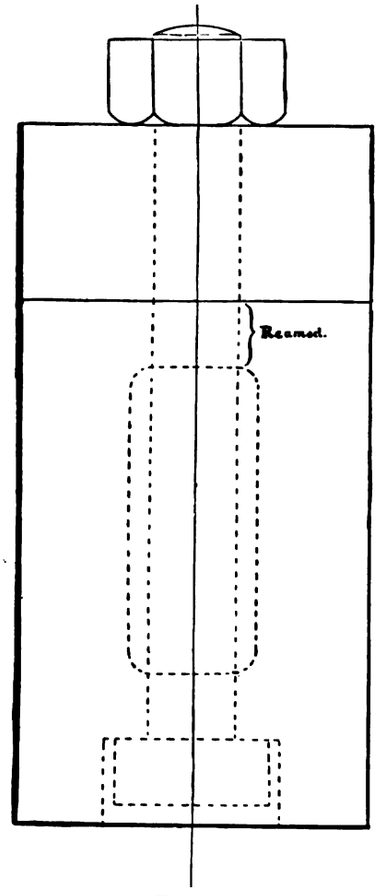

FIG. 28.

attention here to one or two points in reference to the preceding illustrations, and some of those which follow.

1. The holes *not* tapped, through which a bolt passes, are drilled or cored a little larger than the bolt. But it is not necessary in a connected plan to indicate this, (with an exception to be explained presently,) since the double lines would confuse the drawing, without any advantage. The outline of the *bolt* is drawn, and its diameter in all cases marked in figures; it is then the part of the machinist to make the hole *for a bolt of that size.*

2. The holes which *are* tapped must of course be made a little deeper than the length of the entering part of the bolt. But again, confusion would arise from showing this, and the drawing of the bolt being made, it is the mechanic's duty to make the hole deep enough for it.

If separate drawings are made of the parts to be bolted together, the holes are *there* to be laid out of the size and depth actually required.

3. In order that a nut may "draw" or "bind," the bolt must be threaded for a distance a little greater than the depth of the nut.

This being perfectly well understood, and implied by the very existence of the nut, the thread need not be indicated in a connected plan. If detail drawings of the bolts are made, the thread must there be shown, in a manner which will be illustrated farther on.

10. The exceptional case alluded to in the preceding section is illustrated in Fig. 28. The bolt being of considerable length, the hole is "chambered" for some distance to a diameter much greater than that of the bolt. This chambering is therefore shown in the drawing—as is also the "pocket" or recess formed when occasion requires for burying the head of the bolt. In order to secure alignment the upper part of the bolt-hole is often reamed so as just to permit the bolt (which, however, need not be turned) to pass through: this must be noted on the drawing, as in the figure.

11. The reader must not be surprised if he is solemnly assured by many that the hex-

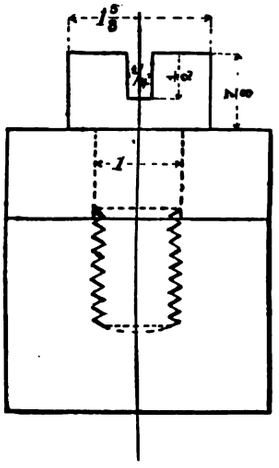

FIG. 29.

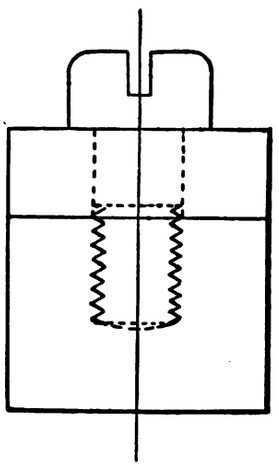

FIG. 30.

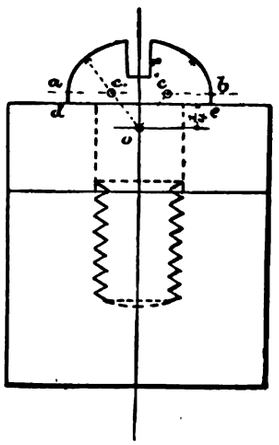

FIG. 31.

agonal nuts and heads herein shown are all wrong side up, and that in machinery making any pretension to finish, the corners of the *top* instead of the bottom should be rounded off. Also that the method above described of preventing the lower corners from scraping is not the right method, but that this object ought to be accomplished by turning the lower side so as to form a very thin cylindrical collar of a diameter equal to the inscribed circle of the hexagon. This is merely a matter of taste; and neither style has any practical advantage over the other.

12. Screw-driver Heads.—Bolts with round heads, slotted for the application of a screw-driver, are rarely used in heavy work, but those of small size, called "machine screws," are extensively employed in lighter constructions. Even in that case, they should be correctly represented; and they are occasionally met with up to $1\frac{1}{4}$ inches in diameter; most frequently when the head must be countersunk.

Suitable proportions are shown in Fig. 29; calling the diameter of the bolt 1, as usual that of the cylindrical head is $1\frac{5}{8}$, its depth $\frac{7}{8}$, the slot being $\frac{1}{4}$ wide and $\frac{1}{8}$ deep.

By rounding off the top corners with a radius of $\frac{1}{4}$, as in Fig. 30, we have the "fillister-headed" machine screw, the smaller sizes of which are largely used in model work and light mechanism of a similar kind. The heads of these small screws are also sometimes made of a hemispherical form. But if made *exactly* so, the effect is unpleasing, and a preferable contour is given in Fig. 31. The diameter of the head is $1\frac{5}{8}$, and the sides *da*, *cb*, are vertical for a distance of $\frac{1}{8}$. From centres *e e* on *ab* two circular arcs are drawn with a radius of $\frac{1}{2}$, and these are joined by an arc about a centre *o* on the centre line, lying $\frac{1}{4}$ below the bottom of the head: the slot is $\frac{1}{4}$ wide and $\frac{5}{8}$ deep.

13. By counterboring the piece against which it bears, the cylindrical head shown in Fig. 29 may be partially buried—or even entirely if that piece be thick enough. If it be not thick enough, and it be desirable nevertheless to make "flush work," the conical head, Fig. 32, is

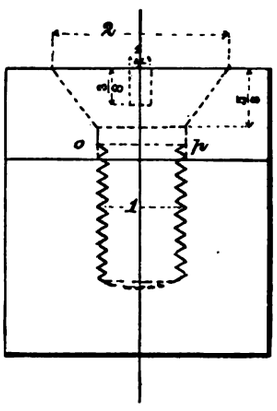

FIG. 32.

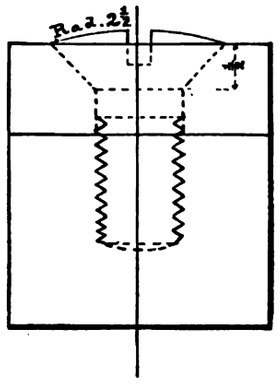

FIG. 33.

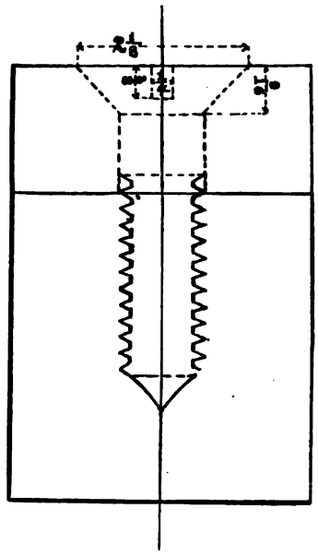

FIG. 34.

used. The larger diameter is 2, depth of frustum $\frac{5}{8}$, slot $\frac{1}{4}$ wide and $\frac{5}{8}$ deep. If not required to be absolutely flush, the depth of the frustum may be made $\frac{1}{2}$, as in Fig. 33, and the top of the head finished off with a circular arc having a radius of $2\frac{1}{2}$, the size of the slot remaining unchanged.

14. Wood-screws.—The angle of the Vs, in representing the wood-screw, Fig. 34, should be less than 60°, say about 45°, and the threads separated by a small distance at the bottom. The "gimlet point" is indicated by finishing the end of the screw with two concave arcs as shown; the slope of the conical head is 45°, the depth $\frac{9}{16}$ of the diameter of the screw; the slot $\frac{1}{4}$ wide and $\frac{5}{8}$ deep. These dimensions are larger than those found in many of the screws in market, a very common defect in which is a slot too small to give sufficient bearing surface, the result being that the edges yield and the slot quickly becomes useless; a most vexatious experience familiar to all.

15. Detail Drawings of Screws.—In many machine-shops it is customary to make, for any engine or machine in hand, a "bolt sheet," showing all the different kinds and sizes of bolts, nuts, screws, etc., required, with the number of each.

A good practical method of indicating the screw-thread is shown in Fig. 35; the exterior outline of the bolt being drawn in ink, the guiding lines for the bottoms of the threads are lightly pencilled; but instead of drawing the Vs, the threads are indicated by a series of parallel lines, alternately long and short, properly inclined as required by the pitch. The inclination is very readily determined as shown at the right of the figure; the section *ebc* of a single thread being drawn with the 60° triangle, then since the root on one side of the bolt is opposite the crest on the other, *ca* is drawn "square across," and *ab* is the desired slope. Setting the triangle by this line, then, the parallels are drawn at once in ink, the spacing being done by the eye, as in sectioning. Since the crests of the threads cast shadows, the *long* lines should be made heavy; which is best done by going again over each with the pen, as soon as it is drawn.

16. This is a purely conventional way of indicating a screw-thread; it is not, and does not pretend to be, a *drawing* of it in any proper sense; but it answers the purpose in view just as well as the most accurate representation.

Moreover, at a little distance a drawing of a small screw thus made actually looks like a screw, whether it is like it or not—much more so than it would be likely to were

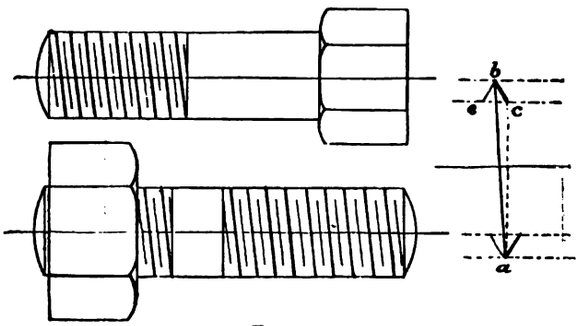

FIG. 35.

the Vs drawn with the triangle, especially if the pitch be fine; in which case the most painful accuracy in the use of the instruments is necessary to avoid variations in the diameter, which are always conspicuous even if small, and utterly ruinous to the effect: whereas trifling errors in the spacing of the parallel lines do not force themselves upon the attention to anything like the same extent.

17. If the bolt is very large, the above modes of representing it in full-size drawings are not eligible. It is, however, very rarely that one is used of such dimensions as to make it worth while to construct an exact projection of it, introducing all the details of the flattening of the crest at the top and the groove at the bottom, the helical curves of the thread, etc. As a compromise between this and the preceding processes, that shown in Fig. 36 may be used with good effect.

This consists in laying out the section of a "full sharp" V-threaded screw, which is carefully inked in with the aid of the 60° triangle, after which the tops of the threads are joined by one series of parallels (made heavy, as being shadow-lines), and the bottoms by another series, which of course have a slightly different inclination.

It is, certainly, possible that a bolt may be required, in very massive machinery, so large that it may be desirable to show the outline in this manner even in a plan where

the bolt is drawn "in place." But this should not be done if the pitch be much if any less than half an inch, or the effect will be merely that of a mass of dots; and far less distinct, while much more laborious, than that of the method first described.

18. Exact Drawing of a Nut.—On the other hand, if the nut be very large, it may be worth while to represent precisely the effect of turning it off to a spherical form at the end.

Let the axis of the hexagonal prism, and the dotted great circle of the sphere whose centre is *c* in Fig. 37, lie in the plane of the paper, *LL* representing a plane perpendicular to the axis. Then all the edges of the prism pierce the sphere at the same distance

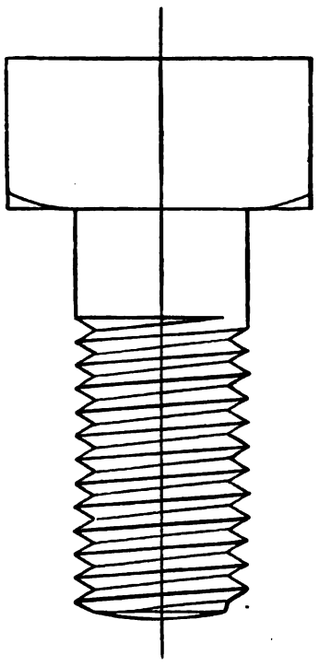

FIG. 36.

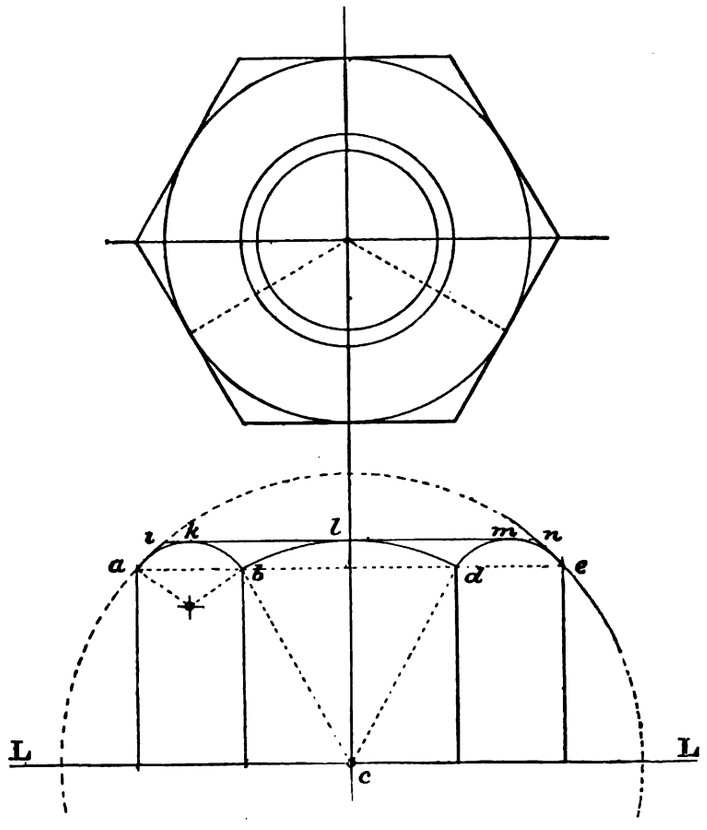

FIG. 37.

from *LL*, to which therefore *abde* will be parallel. The front face of the prism cuts from the sphere a small circle, of which the arc *bld*, whose centre is *c*, will be visible, and since this face is parallel to the paper, this arc will be seen in its true form.

Equal circles will be cut from the sphere by the other visible faces; but since these faces are inclined to the paper, the arcs *akb*, *dme*, will, strictly, appear as parts of ellipses, the middle points *k*, *m*, of these arcs being the extremities of the major axes. The distance of these points from *LL* will of course be equal to *cl*; therefore if the nut be finished, as is usual, by a transverse plane through *l*, it will suffice in practice to draw through that point the horizontal line *in*, and to draw *akb* as a circular arc tan-

gent to *in*; finding the centre by trial and error. Thus it is seen that the short-hand representation adopted in the working drawing differs from this exact construction only in the omission of the portions *aik*, *cnm*, and the substitution of two arcs of a shorter radius for the flatter arc *bld:* but these apparent trifles will be found to effect a material saving of time and trouble where many nuts of the same size are to be drawn.

19. Rivets.—By the use of the hand-hammer, the form given to the outer head of a rivet is approximately conical; and it may be represented in either of the two ways shown in Fig. 38, the diameter of the base of the cone being, in each, twice that of the rivet, which is taken as unity.

The one on the left is more readily drawn, the head being an exact cone whose altitude is $\frac{5}{4}$. The one on the right is a stronger form, bounded by two circular arcs, each struck with a radius of $1\frac{5}{4}$ about a centre on the opposite side of the outline of the body of the rivet; thus, the arc *ab* is described about *c* as a centre. The lower, or

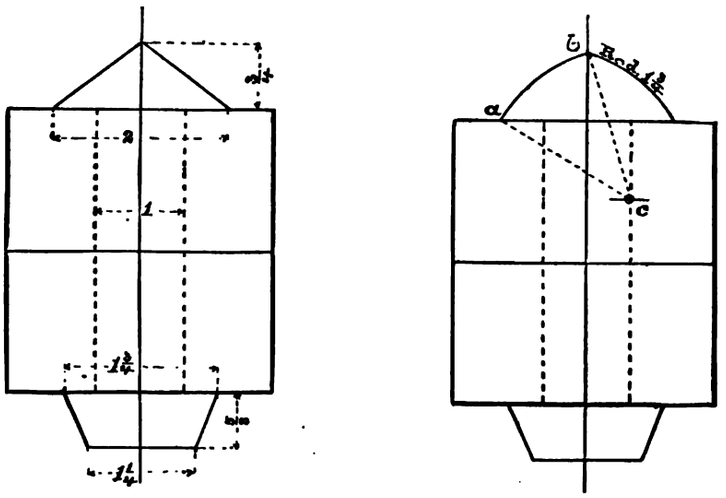

FIG. 38.

original, head of the rivet is in the form of a truncated cone, the larger diameter being $1\frac{3}{4}$, the smaller diameter $1\frac{1}{4}$, and the depth $\frac{5}{8}$.

20. If a die (sometimes called a "snap" or a "button-set") is used instead of the hand-hammer, the "cup-head" thus formed may be represented as shown on the left in Fig. 39. This is not a complete hemisphere, its diameter on the flat face being $1\frac{3}{4}$, and the centre of the curve being $\frac{1}{4}$ below the face.

In machine-riveting the finish may be the same at both ends, as shown on the right in the same figure; and of course a round-headed rivet may be riveted over with the hand-hammer if desired.

21. Countersunk Rivets may be made "dead flush," as shown in the left in Fig. 40, or finished with a slightly convex surface, as shown on the right; the latter being preferable when circumstances admit. In either case, the depth of the countersink is $\frac{1}{8}$, its larger diameter $1\frac{3}{4}$; and the second one has, in addition to the cone thus formed, a projecting spherical swell of which the radius is $2\frac{1}{2}$.

22. It is to be kept in mind, that this chapter relates to the representation and indication of things in the execution of which it is not essential, nor expected, that the mechanic shall be governed by the precise dimensions of the drawing. And in like manner, it is not essential that in adopting the proportions herein suggested, the draughts-

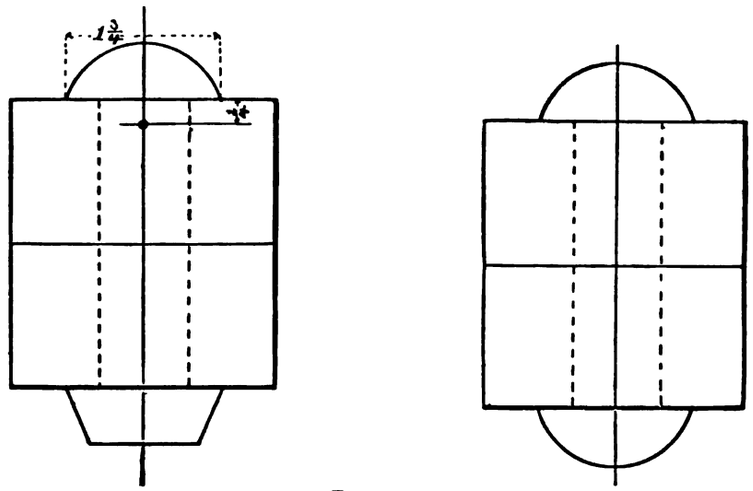

FIG. 39.

man should be over-scrupulous in carrying them out with minute accuracy; common-sense should be exercised in respect to rejecting such insignificant fractions as would in some cases result from a rigid adherence to them. Indeed, it is not advised to make computations at all in these matters: the *diameter* of the bolt or rivet being accurately

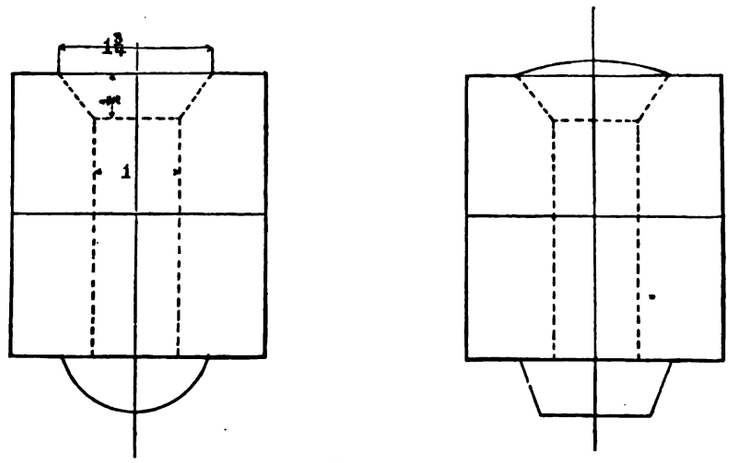

FIG. 40.

set out, the fractions of that magnitude used in laying out the other parts can, with a very little practice, be at once taken up with the compasses, by the eye, with all the precision needed for the purpose of making working plans.

CHAPTER III.

ON FREE-HAND SKETCHING.

Sketching in Proportion.—Its Utility in Designing.—Sketching from Measurement.—Methods of Practising.—Practical Suggestions and Examples.

1. It is supposed by some, that deft handling of instruments of precision alone is required of the mechanical draughtsman. This, however, is an error; no matter how expert he may be in the execution of working plans by rule and compass, the measure of his accomplishments is not yet full if he lack the ability to make good free-hand sketches.

To the designer of a new machine of any degree of complexity, a fair degree of skill in this direction is absolutely essential. He may have the clearest possible conception of the relations of the parts and of the general arrangement of the whole, but without some visible record of that conception, to which reference can be made from time to time, he cannot proceed with any certainty of success in the elaboration of the details. This record is in the nature of a sketch, though not necessarily wholly free-hand Sometimes certain absolute dimensions are assigned as a basis, such for example as the bore and the stroke in a steam-engine.

Or again, definite movements must be provided for, and their elements reduced to settled proportions, as a preliminary; the resulting diagram forming the skeleton of the proposed structure. In either case some use of scale and instruments is of course proper, not to say necessary; but the filling out of this skeleton into the complete body is largely dependent upon free-hand work.

2. Usually this dependence is direct, the designer at once sketching in the general arrangement, for the sake of having something before him as a guide in subsequent operations; and his sketch-plan serves him as the clay serves the sculptor, being subject to erasures and alterations as the development of his scheme may suggest or demand.

In simple cases, however, he may proceed, without this, to construct the details, adding them successively to his skeleton drawing, as each is completed. But whether this be done or not, these details are but the individual figures in the group, and each can be finished with greater ease and certainty in the marble if first modelled in the clay. In designing them, the problems are less comprehensive, but their nature is the same; the skeleton plan indicates certain pins, which must be connected by a link; it locates certain journals, and these must be supported by a frame with suitable bearings; it gives the positions of certain orifices, which are to be joined by pipes with valves; and so on in endless variety of condition and requirement. One of these problems seldom admits of a single absolute solution, which must be accepted to the exclusion of all others. Sometimes tentative methods are necessarily adopted; and in most cases there is a choice of ways and means, so that a judicious selection can be made only by comparison: in either event the utility of reasonably accurate sketches is self-evident, and from the nature of

things it is equally apparent that they can be made most advantageously with the free hand, whether for the use of the maker only, or for submission to the inspection and decision of another.

3. But before attaining to the position of a designer, the draughtsman will in the usual course of events be confronted with circumstances in which such sketching is indispensable. Machines will break down; and it is very frequently necessary to replace a broken piece in the absence of the drawing from which it was made. Or a drawing may be lost after a piece is finished, and a new one is required. If the part in question be small and portable, it might be brought into the drawing-office, and the measurements as taken off be set out at once by scale; but in general this is not practicable, and a sketch must be made and the object measured wherever it may happen to be.

Again, in the case of machines already built, additions or alterations, often called for, require accurate definition of all surroundings, in order that the new parts may go properly into place and action, without interfering with the old ones; and such changes must frequently be made elsewhere than in the original constructing shop, so that the working drawings are inaccessible. It devolves upon the draughtsman to obtain the requisite data as a basis of operations, and his first services are to be rendered, not with his drawing apparatus, but with the mechanic's callipers, squares and rules, wherewith he makes the measurements to be noted on a free-hand sketch. And he who can do this well,—who can be relied on to make no oversights or mistakes, but to return to the office with a clear, distinct, and accurately figured sketch, so that the work may be proceeded with in perfect confidence, is the fortunate possessor of a most valuable qualification.

4. It is advantageous if there be much of this kind of practice, for it is of threefold utility. Not only are the sketches directly made use of for their special purposes, but in the very process of making them and the necessary measurements, the habit of close observation is cultivated, and, in addition, impressions of relative if not of absolute dimensions insensibly fix themselves in the mind, and what may be called a sense of proportion is developed, which to the designer is of the greatest value. For in planning, it is perfectly clear that those sketches are the best which most closely resemble the drawings when finally worked out, since the latter must embody the results of calculations based upon the known properties of materials and the conditions that must be fulfilled. And in making them, the free hand is guided in unconscious conformity with the results of experience and with unwritten deductions from successful practice, just as the style of a writer is influenced without his knowledge by the books he has read; and the more extensive and varied the store of precedents, the better is it likely to be guided. And be it understood, that this acquisition does not make the designer a copyist, any more than a wide range of reading makes a plagiarist of an author; but the one is more likely to put his original conceptions into good practical forms, and the other to put his original thoughts into terse and telling words.

5. In "sketching from measurement," the dimensions are always given in figures; so that the scale drawing must be like the object, whether the sketch is or not. Whence some make the inference, and what is worse they act upon it too, that care with the lines is useless if only the figures are right; and are content with records so rude that no one

else can read them, and they themselves cannot do it after a short time has elapsed. They tacitly assume that he who makes the sketch is also to make the scale drawing, and to do it immediately; neither of which is by any means always the case,—and even if it were, this course is simply throwing away an opportunity of improvement.

It is not the intention that any reader hereof shall make so gross an error. Nothing but the most extreme urgency can excuse such slovenly work, and in all ordinary cases there is time to do it at least fairly well. A good sketch is a permanent record, and either the maker or any one else should be able to work from it at any time: and no draughtsman who desires to improve will permit himself to make one which will not pass this test.

6. The power to sketch new details in good mechanical proportion, previously mentioned as so valuable to the designer, may be greatly increased by practice. And the following naturally suggest themselves as lines in which such practice may be followed to advantage.

1. *Making free-hand copies of working drawings.*

The benefit of this is evident from the fact already stated, that the object in planning is to make sketches which shall serve as guides in making the scale drawings. It need hardly be said that in thus copying, the proportions should be preserved as closely as possible, but the scale may be advantageously varied.

2. *Making sketches from memory.*

This will be found a most beneficial exercise, either for the student or the professional draughtsman. The former may take any good detail drawing, and after careful examination and study of its various parts and their dimensions, subsequently make sketches as nearly in correct proportion as he can, without referenee to the original. The latter may do the same in relation to any plans upon which he may be engaged during the day. The dimensions should be written in and verified by subsequent comparison with the original.

3. *Sketching from the object without measuring.*

This affords the best of training for both eye and hand. It is to be understood that working sketches, not perspective representations, are to be made. If the object, which may be any detail of machinery that happens to be accessible, is small, it is excellent practice to make the sketch as nearly of the exact size as possible: *and after it is completed,* to go over it with a scale and see how close the approximation is. If the piece be large, the sketch should be reduced, and subsequently tested in a similar manner; in doing this, the scale of reduction is determined by comparing the magnitude of some leading part in the sketch, as for instance the diameter of a journal, with its actual size: other parts ought of course to be found reduced in the same ratio.

7. This last must not be confounded with the ordinary operation of "sketching from measurement," previously spoken of, although in some respects similar. It is to be regarded as an exercise pure and simple, and its object would be defeated were the measurements taken beforehand; nor is rapidity, at least in the beginning, a special desideratum, although ultimately it is a point of some consequence. Whereas in the other case time is usually an important item, and a material saving in this respect may often be made by taking some of the leading dimensions before beginning the sketch; besides, the main object here is to obtain a record of the measurements, which must be figured in, clearly and without the possibility of erroneous interpretation. This is absolutely indispensable; if it can be done,

and the sketch still have all parts in correct proportion, so much the better. But this is not always the case, and, as will be explained presently, advantages may often be gained by purposely sketching out of proportion, which also the draughtsman should know how and when to do. Such liberties, it is needless to say, are wholly out of the question in the practice of the preceding exercise.

PRACTICAL SUGGESTIONS.

8. It will have been gathered from the foregoing, that in general a good sketch is equivalent to a working drawing made with the free hand instead of by the aid of instruments: with the one as with the other, the object is to show what to do and how to do it, and neither is perfect if in any particular there is a deficiency or a doubt. But experience proves that one may be quite competent to make a drawing of any mechanical detail from a figured sketch, and yet fail to produce a satisfactory sketch if the piece itself be placed before him. Just as with everything else, practice is necessary in order to do this with facility; written instructions could hardly be made to cover every contingency, but still some hints may be useful to the novice, and enable him to avoid many errors unfortunately too common. The causes of such failures are various; but one of the most prominent is a misconception of what is wanted.

Beginners are very apt to think that an *exact duplicate* is to be made of what they are required to sketch, and to expend much labor in measuring minutiæ of no real importance; such for instance as variations in the thickness of rough castings or unfinished forgings, which are unavoidable, and deviations from symmetry without apparent reason, which may be due to inaccurate workmanship. Such precise duplication is rarely required. In making any part of a machine from a working drawing, in ordinary cases special accuracy is necessary in regard to certain dimensions on account of their relation to other parts, while in many particulars slight deviations from the drawing may be of trifling moment.

The object, then, is usually gained if the *original drawing* can be reproduced from the sketch, and the making of the latter is greatly facilitated by a proper distinction between essentials and non-essentials.

9. Another source of difficulty is the fact that the centre lines, which in the drawing are before the eye and often furnish a key to the laying out of much of the work, do not exist in the finished piece. Consequently the beginner is apt either to forget them, or, by measuring from rough surfaces, or similar unreliable methods, to fail in securing data from which they can be laid down in correct relation to each other or to some definite base line. In making the drawing, the very first step is to locate these centre lines; and so in making the sketch, their positions should be determined at once, and other measurements made in reference to them. This very often results in proving with practical certainty that parts which actually are not symmetrical about these lines were intended to be so, the observed irregularities being due to errors of workmanship or to accidental causes, such as shifting of cores or prints, unequal contraction of castings, and the like: in which case the labor of measuring such deviations is saved, while the sketch itself is all the better.

10. Another oversight consists in omitting to verify measurements by comparison or otherwise, to make sure that all agree with each other. It is very often impossible to take a necessary dimension directly, and it must be reached in a roundabout manner, by making several different ones and then adding some and subtracting others. This being done for this specific purpose; it may also occur that in measuring other parts, a second set of figures is obtained by manipulation with which the same dimension can be ascertained. Now, it is very disagreeable, on attempting to work from the sketch, to find these results at variance with each other: this should be found out before, and the error corrected. And it hardly need be added that care should always be taken to see that the sum of a number of consecutive dimensions is equal to the actual total as determined by measurement.

11. In regard to the number of dimensions to be taken, there are errors of redundance as well as of deficiency. Beginners not only, but occasionally those of considerable experience, will sometimes cover a sketch with superfluous figures, and sometimes they do not put down enough. Of the two, the former is preferable, as being on the safe side, always provided that there are no discrepancies; it is better to waste the time required to make a dozen useless measurements, than to run the risk of omitting one that may prove essential—for an opportunity may not offer to do the work over again, and if a figure be lacking it is tolerably certain to be among the first ones wanted in laying out the drawing.

12. The novice is often at a loss to decide what views ought to be sketched, and how they should be arranged in relation to each other.

This matter is determined precisely as in the case of the original working drawings; the sketches are complete only when they contain all the data which are requisite in laying out a drawing from which new pieces could be made with the certainty that they could be substituted for those measured.

And be it observed that the evils of a slavish observance of the laws of projection, great enough in making drawings, are still more pronounced in the making of sketches. All that has been said in regard to the former applies with added emphasis to the matter now under consideration: by following the suggestions contained in the preceding chapters, sketches may be kept free from a vast amount of useless rubbish, the introduction of which is a sinful waste of valuable time.

13. As previously remarked, this matter cannot well be reduced to the form of abstract rules of procedure. Two or three general principles, however, may be deduced from what has been set forth, which apply in nearly all cases.

(1) Special care is requisite in measuring those portions of any detached pieces which are fitted to other parts of the machine.

(2) Centre lines and lines of symmetry, when such exist, should be carefully located.

(3) All measurements should be made from centre lines or faced surfaces when possible.

(4) Measurements should be verified by comparison, and all discrepancies corrected.

14. It is very desirable that sketches from measurement should be reasonably compact; and by skilful management it will be found practicable to make distinctly figured and complete free-hand records of even massive machinery on the pages of a pocket note-book.

It is not, however, to be supposed that this can be accomplished if all parts are drawn in

due proportion and upon the same scale. Nor is it imperative that anything approaching to this should be attempted; if it can be done, as has already been stated, it is well to do it; but if not, such liberties may be taken with the proportions as circumstances may dictate.

This can best be made clear by example, as no general rules can be laid down for this either: and the following figures, which are *fac-similes* of fair free-hand sketches, are given with the view of illustrating to some extent not only what may be done in this respect, but some other points previously alluded to, as well as one or two which have not been mentioned.

SKETCH NO. 1.

15. In Fig. 41 is shown a valve-stem for a large engine, with a circular collar fitted to a conical portion of the stem near the middle: both ends are threaded and provided with nuts.

In such a case as this, the diameter may be exaggerated and the length contracted; as otherwise the sketch would be inconveniently long, or else so narrow that the figures could

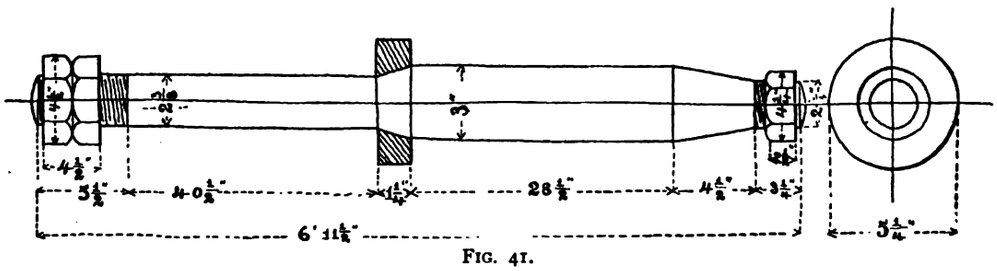

FIG. 41.

not be distinctly written in. This is equivalent to drawing the lengths by one scale and the breadths by another, a familiar expedient in topographical work. But here it is not necessary to preserve the proportions which actually exist between the different parts into which the total length is divided.

The collar is shown in section in its proper place, and an end view of it is also given at the right. The valve-stem being turned, and the nuts hexagonal, no other view of either is necessary.

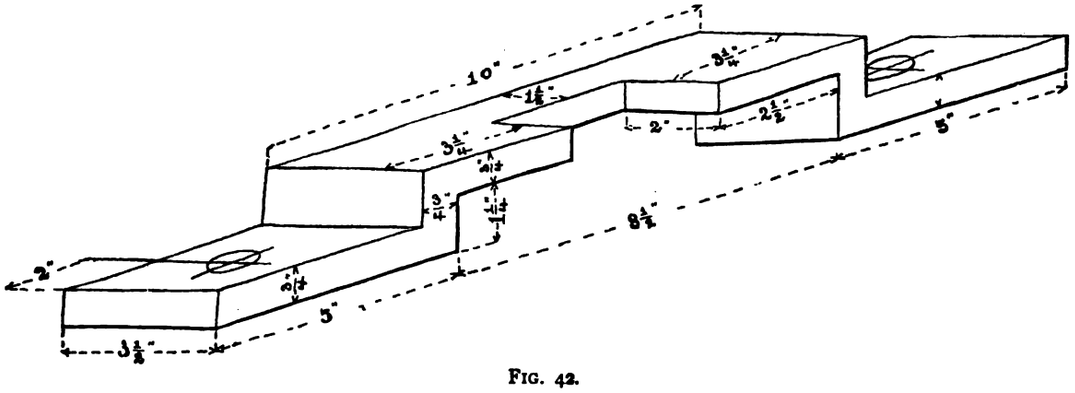

FIG. 42.

SKETCH NO. 2.

16. A simple bridge-piece, of rectangular section, with a notch cut in one side of the raised part, and a bolt-hole in each end, is shown in Fig. 42.

This is a case in which a single view is sufficient, when drawn in oblique projection, or what is known as "cavalier perspective." It is not properly perspective, however, as the oblique lines, representing those lines of the object which are in space perpendicular to the plane of the paper, are parallel instead of convergent.

This method is often extremely convenient, when applied as in this case to objects bounded by lines and planes at right angles to each other.

It conveys the meaning very clearly, and the drawing may be worked from directly, since, all the oblique lines being parallel, and those which are equal always appearing equal, they may be set off in their true lengths when a scale is used, and the actual dimensions may with perfect propriety be written on a sketch thus made.

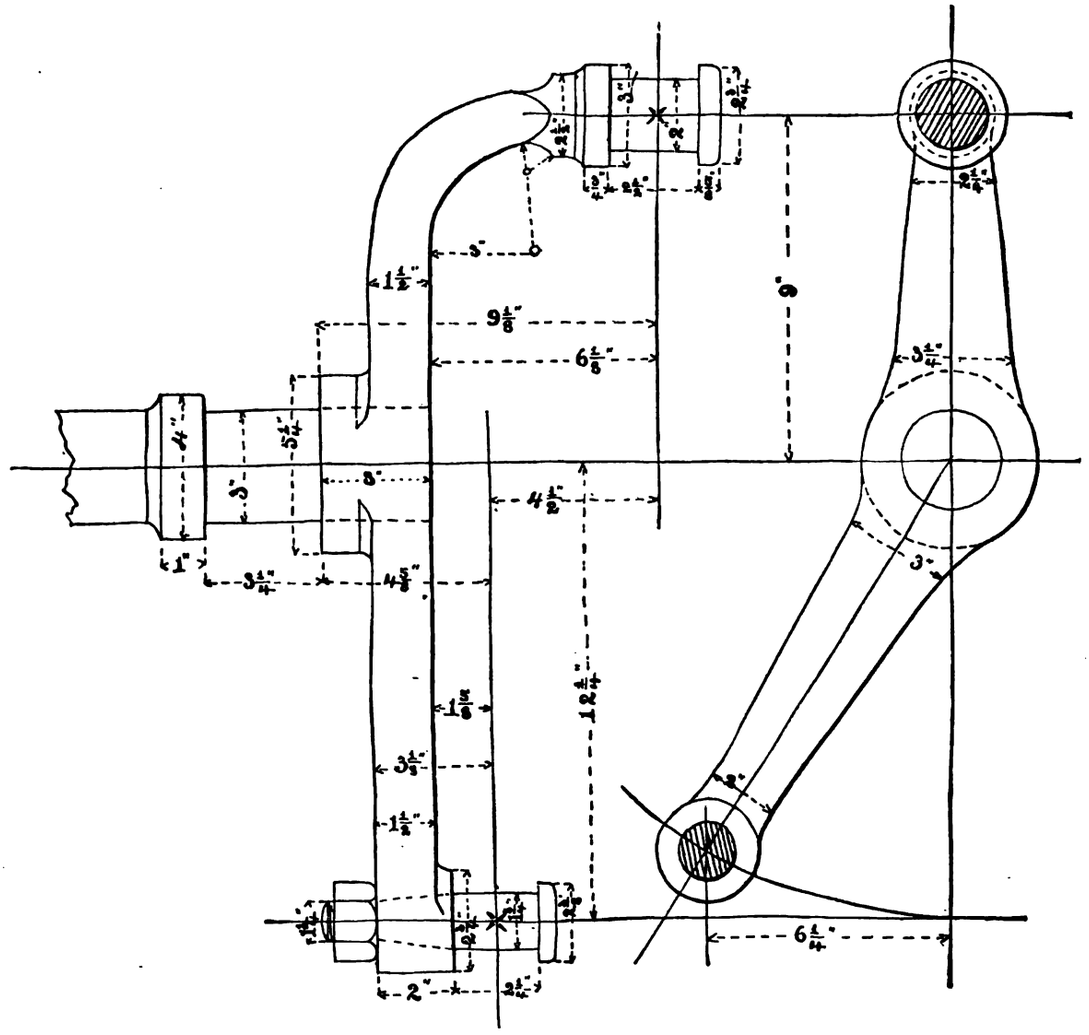

FIG. 43.

SKETCH NO. 3.

17. A lever, of which the two arms make an obtuse angle, and one is bent at right angles, so that its pin is parallel to the shaft, is shown in Fig. 43.

Two views suffice to define the construction of this somewhat crooked piece, so that no questions need be asked.

In the end view on the right, the bent arm is placed with its centre line vertical; the other arm is shown in its true length and position, and both pins are drawn in section, thus

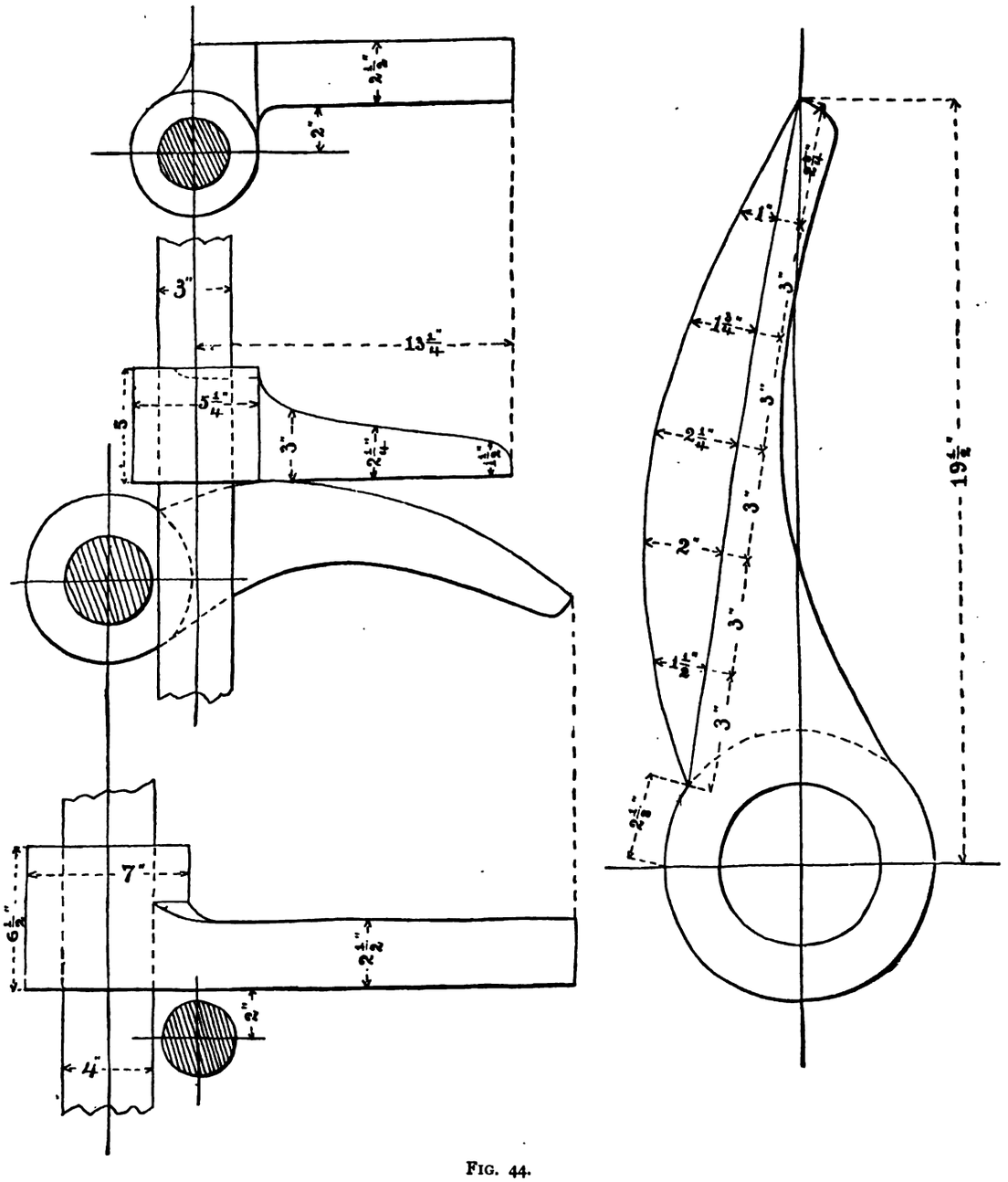

FIG. 44.

avoiding the necessity of showing the outward collars and dotting the pins. This last item is more important than it perhaps seems, as the pins are the more prominent parts, and by thus making them conspicuous the whole is rendered more clear and striking.

In the side view, the inclined lever is not projected in its true position, but *is shown in its true length*, just as though in the end view its centre line were also vertical.

Particular attention is called to the circumstance that in this view vertical centre lines are drawn through the middle points of the lengths of the pins; and the distance of these from each other, and of each from the face of the central hub of the lever, are given.

These vertical lines locate the planes of rotation, and their positions in drawings of other parts of the machine which are connected with these pins must obviously agree with those here shown.

SKETCH NO. 4.

18. In Fig. 44 are shown a "lifting toe," and its cam or "wiper," such as are used in the valve gear of the common beam-engine.

On the left there is sketched a side view of these two pieces, with a portion of the lifting rod to which the toe is attached. Above this is a top view of the toe, the lifting rod being given in section as though cut off above the toe. Below it is shown a top view of the wiper, a section of the lifting rod being also placed in its proper position relatively to the wiper, a part of whose rock-shaft is likewise given: a section of the latter is seen in the side view.

The form of the curved face of the wiper is important; and in order to define it with precision, an enlarged sketch of it is made on the right. In this, a chord of the curved acting face is drawn, and the "offsets," or perpendicular distances from this chord to the curve, are given at definite intervals.

This chord at one extremity cuts the outer circumference of the hub of the wiper: and in order to define the angle at which the wiper is placed, a line is drawn from the other extremity of the chord through the centre of the shaft; also a perpendicular to this line, passing through the centre and cutting the circumference, in another point: and the distance from this last point to the first-mentioned extremity of the chord is figured in.

SKETCH NO. 5.

19. The subject of this sketch is the cross-head of a steam-engine, formed of a transverse piece forged on the piston-rod, which is also shown in Fig. 45.

Two views are in this case also made to serve all purposes. In the side view the length of the piston-rod is contracted, it being quite needless to show it in due proportion to the other parts. And while the idea of the general contour of the cross-head is reasonably well indicated, no attempt has been made to preserve the relative sizes, which are sketched so as to accommodate the figuring, upon which everything ultimately depends in making a drawing to scale.

In the end view, the piston-rod is shown in section, and so also is a part of the upper end of the cross-head, the lower part being drawn in elevation. Here, again, everything is made subservient to the easy and clear introduction of the figures, and to the keeping of the whole sketch within due limits as to size.

SKETCH NO. 6.

20. In Fig. 46 is shown a pillow-block, or bracket, of a somewhat peculiar form, the cap being inclined at an angle of 45° to the horizontal.

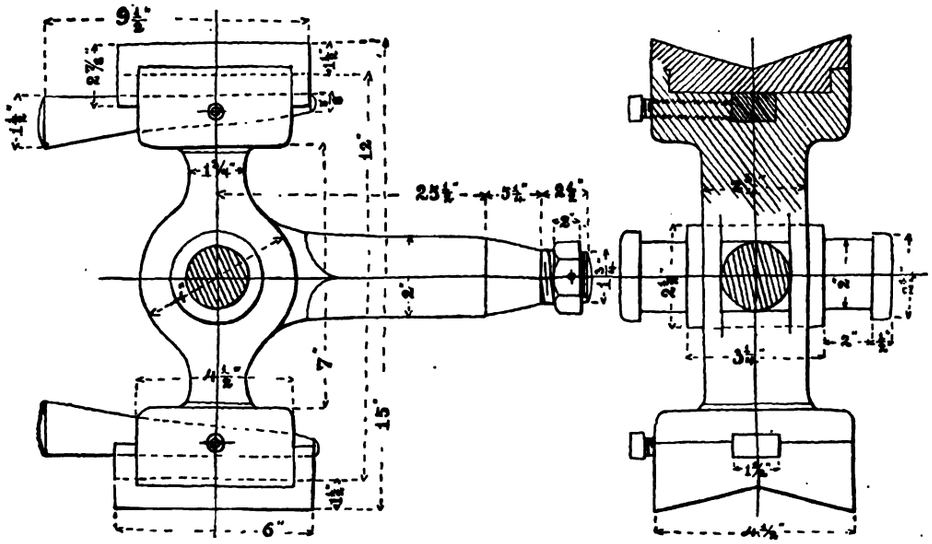
9½"
2⅞"
1¼"
12"
25½"
3½"
2½"
2"
7"
15"
6"
2½"
2"
3½"
2"

FIG. 45.

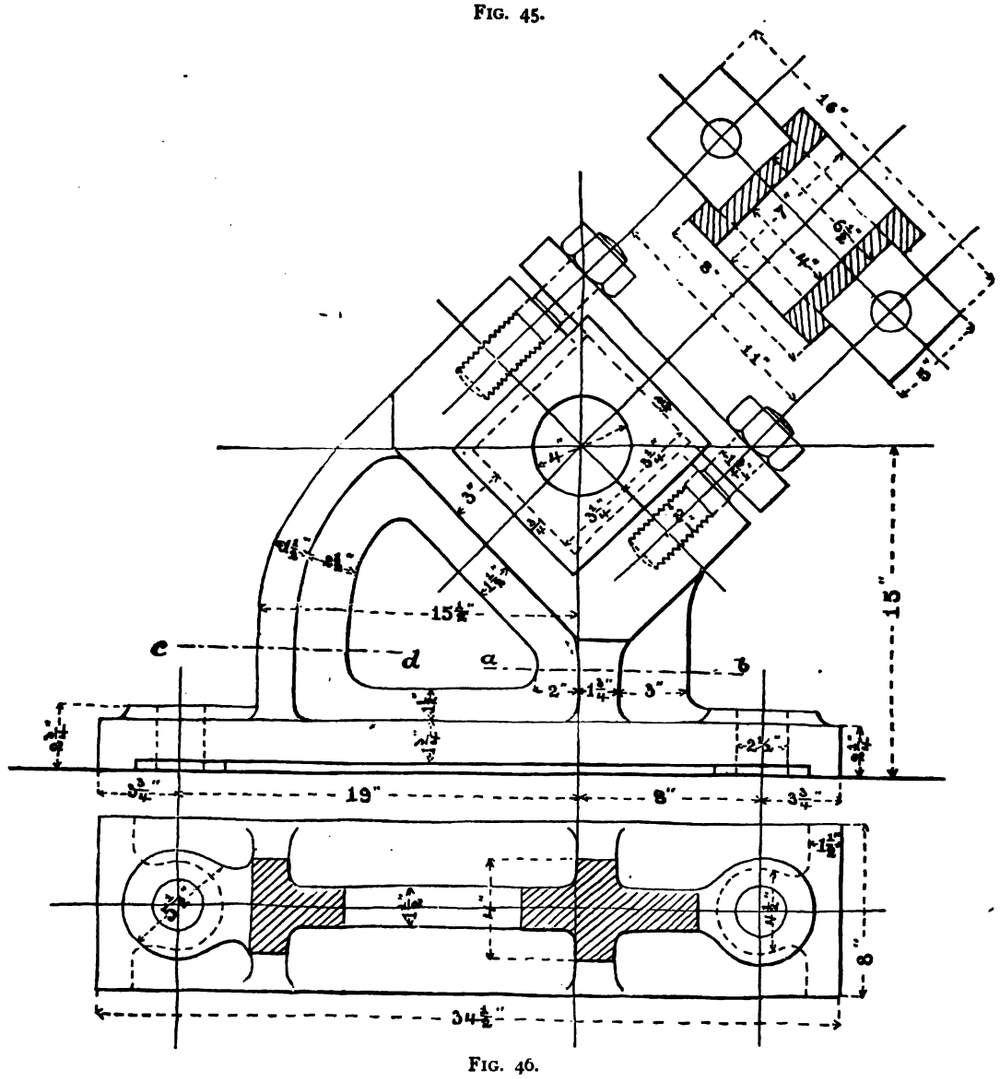
16"
8"
11"
6"
15½"
c
d
a
b
2"
1¾"
3"
15"
19"
8"
3¾"
8"
34½"

FIG. 46.

In such a case as this, it is at once apparent that while the front view is in the highest degree explanatory, a view from either the right, the left, or above, would be not only troublesome to sketch, but of very little service in the way of imparting information, if it were made.

But drawing a centre line perpendicular to the cap, it is equally clear that a direct view of the bearing from the upper side, in the direction of that line, will convey all that is lacking as to the construction of the brasses and the solid metal by which they are surrounded; the cap may be omitted, if, as is usual and as here supposed, its outline be the same as that of the bearing. This view is made more distinct by supposing the upper brass to be removed, and showing a section of the lower one, as though a film had been planed off its upper face.

The centre lines of the bolts are drawn and the distance between them given: which is sufficient, as when there is no indication to the contrary, it is always understood that they are equidistant from the main centre line; and the same holds true in regard to other dimensions, such as the breadth of the bearing, the diameter of the bore, the width of the brasses: when practicable, the whole should be given, as in this illustration, and not the halves, or distances from the centre line.

21. But when, as in the side view, the main centre line (in this case the vertical one) is not a line of symmetry for all parts, then the unequal distances from it to those lines which it is necessary to locate should be given: as for instance the centre lines of the holding-down bolts.

Now, the base of this bracket being horizontal, a top view of it is essential. But in order to avoid the introduction of a foreshortened view of the bearing, cap, etc., the upper part is cut off, by the two horizontal planes *ab*, *cd*; and then looking perpendicularly down upon what is left, a perfectly clear idea is gained of the structure of the supporting ribs and of the whole arrangement of the base, the facing strips on the bottom being dotted in. From this faced surface the vertical distance to the centre line of the shaft is measured.

In sketching such an arrangement as this, there is no reason for deviating from the true proportions as they actually exist, since all the parts are so compact that there is no necessity to reduce any one of them for the sake of economizing space, nor is there any for enlarging others in order to make the figures clear.

Opportunities of this nature should always be improved for the purpose of gaining practice and skill in accurate free-hand drawing, and as much care taken as time will permit to sketch in proportion, for reasons already explained.

SKETCH NO. 7.

23. In Fig. 47 are shown all the sketches necessary for the barrel of an air-pump for a marine engine provided with surface condensers.

This is very different from the preceding subject in respect to the possibility of sketching in proportion; the diameter and the length being so great, as compared with the thickness of the metal, the breadth of the flanges, and the sizes of the bolts, that any attempt to show the whole in correct relations would be preposterous.

Therefore the effort is not made. A longitudinal section is absolutely necessary, and the thickness of metal in different parts, as well as the joints and fastenings, must be clearly shown.

Now, the barrel of the pump is round, and it has a curved nozzle or discharge-pipe, of rectangular section, on one side near the top. The bore of the pump, and the number and

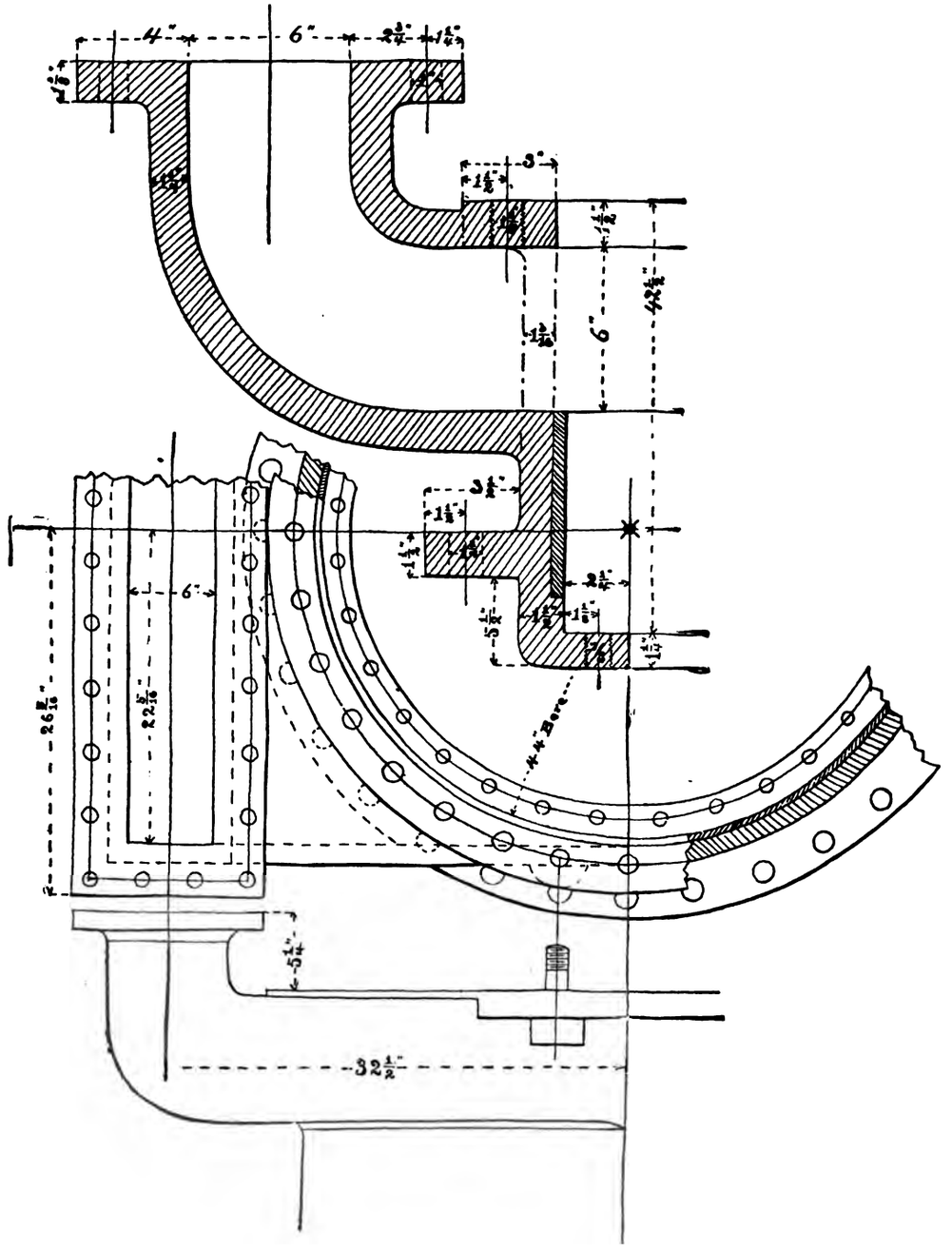

FIG. 47.

arrangement of the bolts in the flanges, are fully indicated by making a top view of a little more than one quadrant, with a little more than a half of the rectangular discharge-pipe just mentioned. This view is sketched on a small scale in the lower part of Fig. 47: or rather

the central part, for below this top view is given an outside view of the upper part of the barrel, including the upper flange and the discharge-pipe; showing clearly that this last extends only to the main centre line, and also exhibiting a hub which must be provided for one of the standing bolts, which comes directly over the side wall of the nozzle.

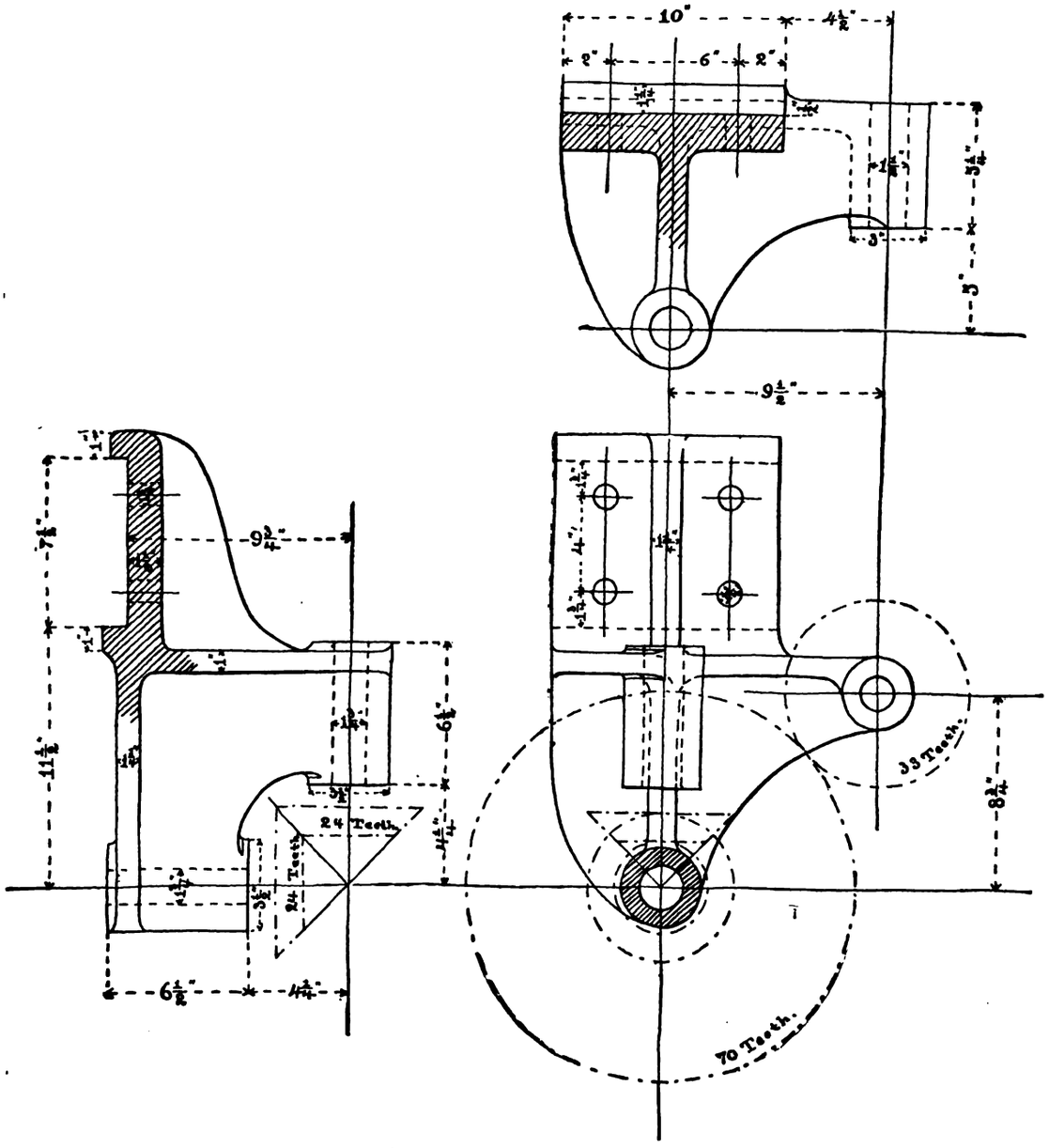

FIG. 48.

Above these is made a sketch on a much larger scale, being a section by the plane *ab*; but a section only of that side on which the discharge-pipe is placed: the form of the section of the opposite side, in so far as it is unlike this one, is indicated by continuing the side wall

of the barrel, above the lower side of the nozzle, in a peculiar style of dotted line, consisting of alternating dashes and dots.

In making this sectional sketch, all the flanges and bolts are indicated, and the dimensions written in: the length is contracted, in order to save in height; and thus the whole is fully recorded within very reasonable limits of space.

SKETCH NO. 8.

In Fig. 48 are given sketches of a bracket provided with three bearings. In the first bearing runs a vertical shaft having at its lower end a mitre-wheel, which engages with a similar wheel on the second shaft; this shaft is horizontal, and carries also a spur-wheel of 70 teeth, engaging with another of 33 teeth on the third shaft, which is parallel to the second.

This example specially illustrates the necessity of locating centre lines with reference to each other and to faced surfaces.

As clearly shown in the side view at the left, this bracket has a faced bearing surface, which is to be bolted against its support; and the first step should be to measure the exact distance of the vertical axis from this face: the second, to measure the distance of the lower horizontal axis below the lower edge of the same faced surface. From these centre lines are measured the distances to the faces of the two bearings shown in that view; and the two mitre-wheels are indicated by dotting in the pitch cones and marking the numbers of their teeth.

The centre line of the third shaft is located, as shown in the front and top views, by measuring its distance to the right of the plane of the other two, and also its distance above the lower horizontal axis, a good check being to measure in addition the direct distance between the two horizontal axes.

The bearing of this third shaft is fully shown in the two views at the right, and therefore is not dotted in, in making the side view at the left; similarly, the lower horizontal bearing, being completely defined in the two lower views, is omitted in the top view: it being a general principle to avoid dotted lines whenever they can be dispensed with.

The pitch circles of the two spur-wheels are shown in the front view at the right: and the numbers of teeth being noted, this sketch contains a complete record of the system of gear-wheels used, so far as the velocity ratios are concerned: which, though not essential to the completeness of the bracket, is, nevertheless, useful information, as indicating the manner in which the wheels, which would be sketched separately, are to be arranged.

SKETCH NO. 9.

In Fig. 49 are shown sketches of a "stationary link" such as is sometimes used as a reversing gear for steam-engines, with the link-block and valve-rod.

This link consists of a slotted arc, connected by means of two short standards to a curved back-piece which is extended into a lever, and secured, by means of a hub formed upon it, to a supporting spindle. The forms of the arc and the back-piece are clearly shown in the upper view at the left: the supporting spindle and the standards are shown in the side view, at the right, where, however, the lever is not dotted in, as it would present a confused and confusing mass of dotted lines.

In order to show this lever and its pin, a top view is given below, in which the back-piece

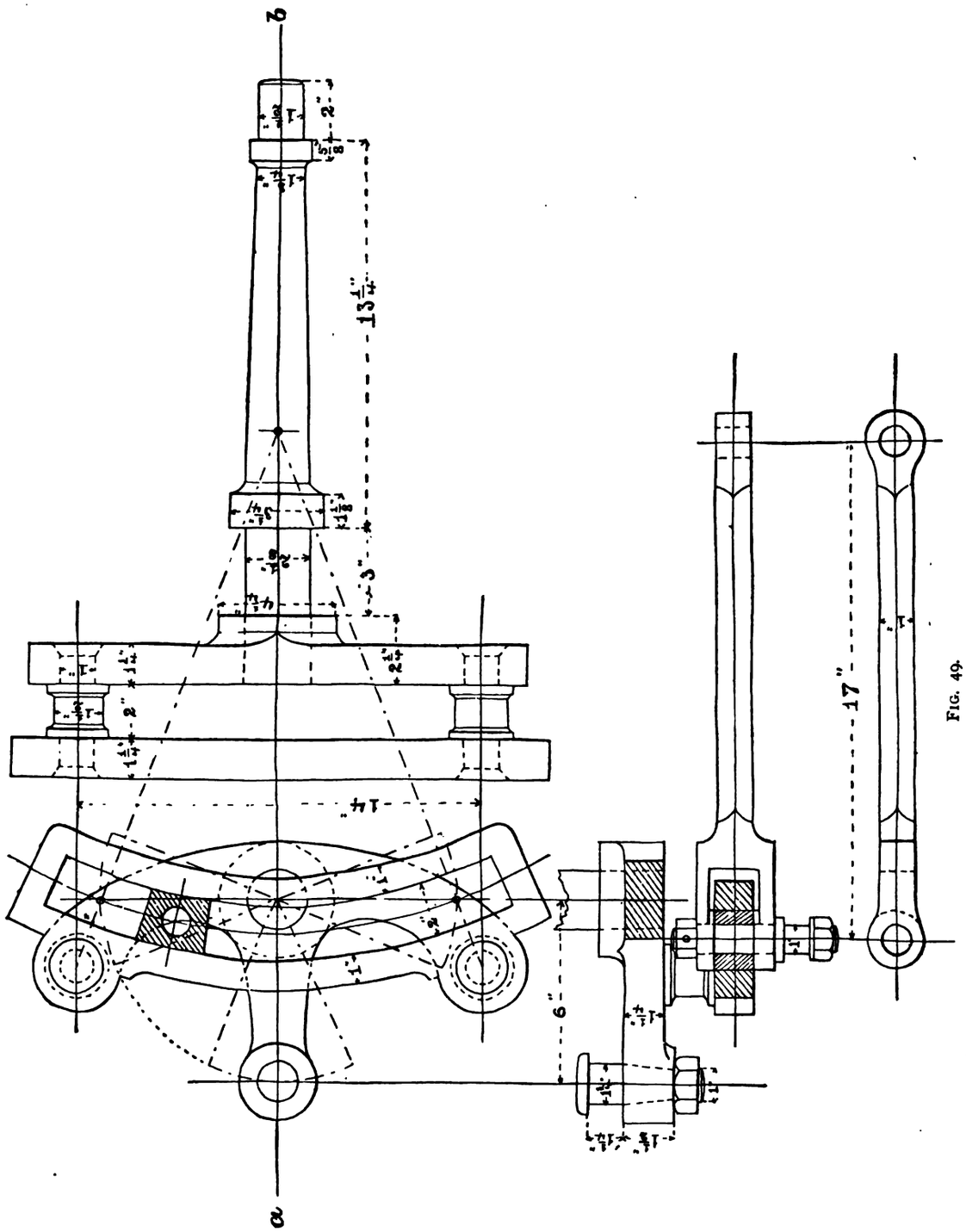

FIG. 49.

is cut off, not through the centre, but *above the hub*. The link itself, however, is cut by the horizontal plane *a b*, in this top view; so also is the link-block, which is here supposed

to be in its central position, although in the front view above it is pushed half way up to its highest position for the sake of perspicuity.

In the top view also the valve-rod is shown, with its pin, but neither of them in section: and finally, a front view of the valve-rod without the pin is given below.

The angular movement of the lever and the link is indicated by dotting in the arcs, and the radii limiting the extreme positions of the lever-pin, and of the link-block pin, in both the lowest and the highest positions. Also the angular movement of the valve-rod in going from "full ahead" to "full back" is similarly indicated by dotting the centre lines for those two positions, the centres of the pins being indicated by minute circles: and thus the sketch conveys a very clear idea of the nature and extent of the movements for which the arrangement is designed.

The dimensions of all the smaller details are not given in this sketch; but attention is called to the arrangement and location of the figures which are given; which will on examination be found sufficient for laying out the link and the principal pieces connected with it.

These few examples will serve to illustrate some of the most important points to be observed in making sketches of details, the nature of the expedients which may be resorted to on occasion for abbreviating the work and saving space, as well as the style in which they can be executed with the free hand when the object is to preserve the due proportions of the parts.

It is to be understood also, that the methods of representation set forth in the two preceding chapters are just as applicable in sketching as in drawing to scale, and many useful hints may be found in the illustrations there given.

In conclusion it may be well to observe, that while skill in free-hand work pure and simple is a most valuable accomplishment, the acquirement of which cannot be too strongly advised; yet the inference must not be drawn that in "sketching from measurement" the use of instruments is under all circumstances prohibited.

It often happens that time is of the utmost consequence, and measurements and records are required in such haste that he who makes them, if not already an expert, cannot in conscience avail himself of the task to train his unskilled hand. In such event, although a scale cannot well be used, the ruler and the compasses may and should be employed: but with the mental resolution that the necessity for so doing shall, at the earliest possible moment, cease to exist.

CHAPTER IV.

DRAWING INSTRUMENTS AND MATERIALS.

1. A great number of appliances can be packed into a case of instruments, if it is only large enough; and a whole treatise might be devoted to an explanation of them. Many of those found in the more expensive cases, though each has ostensibly a purpose, are in fact of pecuniary value only, and of no practical use whatever; notwithstanding which they are very often given such prominence even in works upon drawing as to imply that their possession is desirable. It is proposed here to describe only those instruments which are essential for the ordinary, and sufficient for the extraordinary, occasions of the mechanical draughtsman; and to add some hints as to their selection, for the guidance of those whose judgment has not been trained by experience, because the difference between a good article and one which is radically bad often lies not in the quality or finish, but in points which might be easily overlooked by any one not an expert in its use.

In this as in many other matters true economy consists in procuring the best. There is a vast amount of "cheap" trash in the shops, and he who is wise will leave it there. If he has but a limited sum at command, his best course is, not to buy a "complete set" of inferior quality, but to purchase only what is absolutely indispensable at the time, and add to his stock subsequently as opportunity permits.

The English, French, Swiss, and German instruments have each their distinguishing characteristics of *style*, in regard to the beauty of which tastes differ; but this is not a thing of material consequence. But there are features which are; and instruments of whatever make should possess certain qualities in order to give perfect satisfaction in use. Some of those mentioned are almost always excessively heavy, and this is not good; every piece should be as light as is consistent with the necessary stiffness and freedom from springing. The illustrations that follow represent instruments of the English pattern, but lighter than those of English make are usually found; the exact proportions having been determined by experiment, the weight being gradually reduced until the present limit was reached. They are of American manufacture, and in every respect equal to any in the world.

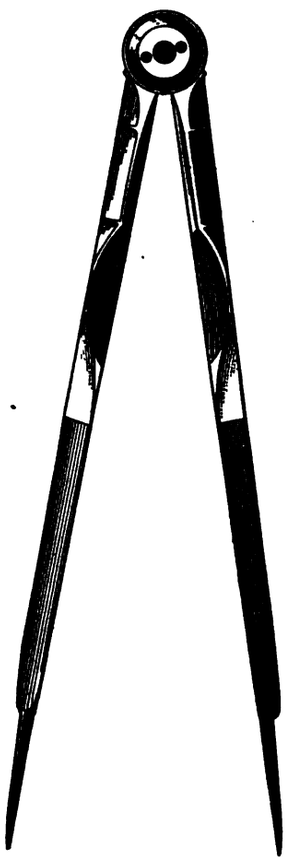

FIG. 50.

2. The Dividers.—Beginning with the "case instruments," the first thing on the list is a pair of dividers, Fig. 50. The construction of this is too familiar to require explanation. The lower part of the leg is of fine steel, the upper part preferably of German silver. The body

of the leg is of triangular form, but for half an inch at the lower end is made round, forming what is known as the English needle-point. The points should close fairly together; they should be as sharp as needles, and *kept* so: their use is not to act as a nut-pick, a drill, or a reamer, as sometimes erroneously supposed, but to make the finest of visible holes *in the surface only* of the paper.

The value of the instrument depends upon the perfection of the joint. This should be so accurately fitted as to move with uniform ease through the whole range of its motion; if it goes easily in one place and sticks in another, or if in either opening or closing from any position the legs resist at first and yield with a start, the instrument is a poor one, let the maker be who he may.

The best form of joint is that shown in the figure, and known as the "double sector joint," the upper part of one leg being provided with two thin leaves of steel, fitting into two slots in the other leg. This requires the best of workmanship, but a good joint of this kind will last indefinitely, and its use is a constant pleasure.

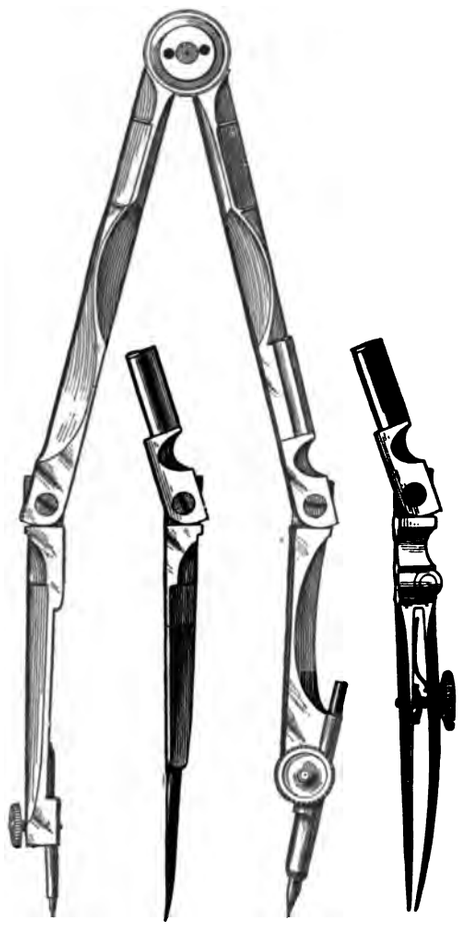

FIG. 51.

In selecting, the joint should be tested as in using; it should retain any position without the least "shakiness," but move with such ease that it can be opened to its full range with the fingers of one hand only, and adjusted, or set to any given measurement, with perfect facility in the same manner.

The most convenient length for ordinary use is about five inches, and a pair of this size should form a part of every set of instruments: if there be another pair, a length of from three and one half to four inches will be found very convenient when making drawings on a small scale.

3. The Compasses.—As above stated, the dividers are used for setting off measurements by pricking the surface of the paper; they are never used for describing circles. The instrument for this purpose is a pair of compasses, Fig. 51. The form and construction are the same as in the dividers, except that one leg is jointed, and the other leg is fitted with three "shifting points," viz., a plain leg, a pen, and a pencil-holder, each of which is also provided with a joint.

These joints are necessary in order that each leg when in use, or at least the lower part of it, may be placed as nearly vertical as possible.

A great many are to be found with joints only in the shifting pieces, the other leg being rigid like that of the dividers; these, too, have their proper place, and that place is in the show-case of the dealer's shop.

The principal joint (that uniting the legs) is made the same as in the dividers, and the same tests should be applied to it in selecting; the joints in the leg and shifting pieces are also best made double, two leaves of steel fitting between three of German silver; they should move with uniformity throughout, but rather less easily than the main joint: they are more liable to disarrangement in handling, and nothing is more vexatious than compasses which are "weak in the knees."

4. The Needle-point with which the permanent leg of the compasses is provided should be most carefully scrutinized. The point itself is separate from the leg, and consists merely of a piece of finely tempered steel wire, which should be quite thick, tapering to a point like that of the dividers at one end; at the lower end a square shoulder is formed, with a very fine and sharp point projecting below it. This point only should enter the paper, and the object of the shoulder is to support the weight of the instrument. Hence the shoulder should be as broad as the diameter of the wire will leave it; and on no account should the lower end of the wire be chamfered or tapered, as it too often is.

The needle-point enters a cylindrical socket in the lower end of the leg of the compasses, and is secured by a set-screw. It should enter this socket with a snug sliding fit, without side shake, and be of such length that the set-screw shall bear against the cylindrical and not against the tapered part.

There is another form of needle-point, in which a socket or a clamp is arranged to hold a common needle; which is mentioned only to warn the reader against it as being in most cases worse than none at all, and in the remainder very little better.

5. The best mode of securing the shifting points in place is by means of the "bayonet joint," which is shown in the figure. The lower end of the short leg to which they are fitted is first drilled to form a short cylindrical socket, and this socket is then sawed through for a short distance, on the outside, allowing a small amount of spring.

The upper end of each shifting point is turned cylindrically to fit the socket, and provided with a feather on the outside, which enters the split above mentioned, being very slightly tapered to secure a tight and reliable fit. This is far more neat, compact, and convenient in use, than the more common device of a binding screw to hold the shifting pieces in place.

If the latter is used, the socket and the neck which enters it should be square in section, and should fit without side shake before the binding screw is tightened; also, let the purchaser see to it that the screws are long enough, and have heads of liberal size.

6. The Shifting Points are three in number, as previously stated, viz.: a plain leg, a pen, and a pencil-holder.

The plain leg is formed like that of the dividers, and like it terminates in an English needle-point. When this piece is used, the movable needle-point of the permanent leg may be reversed, when the whole becomes another pair of dividers, which is sometimes very convenient.

The pen is formed of two blades of steel, through one of which an adjusting screw passes, which is tapped into the other; the whole being precisely like the drawing pen to be more fully described presently, and subject to the same scrutiny and criticism in selecting.

The pencil-holder is in the form of a clamp, consisting of a small tube, which is either a part of the lower piece of this joint, or if made of steel, brazed to it on the outside, at a small

inclination as shown. Both tube and supporting piece are split longitudinally, and a binding screw on the side gives the requisite pressure.

This piece should be most carefully scrutinized, as there are many makers who seem to think that, no matter what the proportions or arrangement, a clamp is a clamp, and one as good as another; and so it is *not*.

In the first place, the tube should be accurately drilled, so that a Faber "instrument lead" may *fit* it, and thus receive uniform pressure at every part of the tube when screwed up.

In the second place, in order to produce this uniform pressure, the binding screw should be placed *opposite the middle of the length of the tube.*

In the third place, that the lead may be held with sufficient firmness, the tube should be *from one half to three fourths of an inch in length*, according to the size of the instrument.

In the fourth place, the lower end of the tube, when the compasses are closed, should be *at least five sixteenths of an inch above the lower end of the needle-point socket on the permanent leg.* Thus the lead will project about three eighths of an inch below the tube; which is necessary in order to sharpen it properly.

In the fifth place, the head of the binding screw should stand well out from the bearing surface, be of liberal size and thickness, and well milled on the edges. And the same is true of all binding screws employed.

7. The above form of pencil-holder is beyond question and beyond comparison the best form. There is another, in which the end of the split tube is made conical, and compressed by screwing over it a tube correspondingly tapered internally. The whole is precisely the same device as that used for securing the movable leads in wood or ivory holders for writing; which purpose it answers admirably. But its application to a pair of compasses is the climax of misdirected ingenuity, and mention is made of it for the sole purpose of cautioning the reader against it. The pencil is to be trimmed to an edge, which must be tangent to the arc to be drawn; and after trimming it is usually a little too short, and requires to be drawn out. With the clamp first described, this adjustment can be readily made, nor is there any danger of disturbing it in tightening the binding screw. But with the device here deprecated, the lead is almost sure to be pushed in, and what is worse, turned partially around; so that in spite of its neat and plausible appearance, it is practically as bad an arrangement as could be adopted.

Another useless piece of furniture is ordinarily added to the compasses. This is the "lengthening bar;" which is a bar of metal, one end fitted to enter the socket of the short leg, the other furnished with a similar socket, to receive the pen or pencil. The object is to increase the range and permit large circles to be drawn: a good object, but a bad expedient. For with this addition the instrument is apt to spring unless excessively heavy: a beam compass is much better.

8. The compasses, if there be but one pair in the case, will be best adapted for general use if about five and a half inches in length. If larger they are too heavy, since in order to prevent springing the weight must be increased in a more rapid ratio than the length.

Smaller ones are extremely serviceable; and a pair of four inches in length, made upon exactly the same lines, will soon come to be highly prized by the possessor; being more convenient than the larger ones for drawing circles a little beyond the range of the spring-bows, and for general use in making drawings on a small scale.

9. The Drawing Pen.—This instrument, as shown in Fig. 52, consists merely of two rather stiff blades of steel, formed out of one piece. Their elasticity keeps them apart, the distance being adjusted by means of the screw, which passes through one blade and is tapped into the other.

FIG. 52.

This is the best form, although its first cost is least. Many pens are made with the outer blade hinged to the inner one, the two being kept apart by a spring. The ostensible advantage is the facility of cleaning them: which is no real advantage, because there is no difficulty in cleaning the others. The jointed pens cost more, and are not as good; because the least wear will permit a sliding movement of one blade over the other, which renders their action uncertain.

The inner edge of the blade into which the screw is tapped should be straight, and in line with the axis: the outer blade should be so curved, as in the figure, that the two shall approach each other most rapidly toward the point. The object is to have a reasonable quantity of ink retained there, so that it will not evaporate too quickly, as it would if the film were thin. The blades should be comparatively broad, and well rounded, at the points, as then they will not wear so rapidly, and will remain longer in condition to make smooth lines, than if they taper to a narrow point. In selecting, they should always be tested to see that they are properly set, and have no tendency to cut or to scratch the paper. The case should contain at least two, and preferably three, pens of different sizes, the smaller being used for the finer lines.

With proper care and usage, the pen will remain for a long time in good working order. It should be held as nearly vertical as possible, that the blades, when they do wear, may wear "square across." For wear they will, and occasionally require to be reset: and if by habitually inclining the pen the blades are thus worn off obliquely, the film of ink in contact with the paper will be bounded by converging instead of parallel lines, and when this is the case to any appreciable extent the line drawn will be no longer smooth and even, but ragged and rough. The sharpening, or "setting," is effected by means of a small fine oilstone, and the secret of success is best learned from the instrument-maker. If the draughtsman in constant employment cannot sharpen his own pens, it is a good plan to have an extra set of them, that he may always have those serviceable which are in use.

10. The Spring-bows. For the smallest work there must be smaller instruments: and the "spring-bows," Figs. 53, 54, and 55, are adapted to the drawing of very small circles, and the subdivision and setting off of minute distances. The legs of these, instead of being jointed together, are formed of one piece of steel, the elasticity keeping them apart, and the radius being adjusted by means of a screw pivoted to one leg, passing through a hole in the other, and provided with a milled thumb-nut. The hole in the outer leg

must be large enough to accommodate the motion of the screw as the angle of the legs varies, and on the outside should be of spherical form, the bearing end of the thumb-nut being correspondingly convex, in the manner of a ball-and-socket joint.

In all these little instruments, the degree of stiffness of the spring is of paramount importance. A very common fault is the making of the legs too thin at the top, the result being a tendency to tremble, and a consequent variation of the radius, often even under the slight pressure required to draw a firm clean line with them. If there be the slightest indication of such weakness at any part of the range, the piece should be peremptorily rejected; it is better that the spring be a little too stiff; but there is not much latitude in that direction either, for too powerful a spring causes the screw and nut to

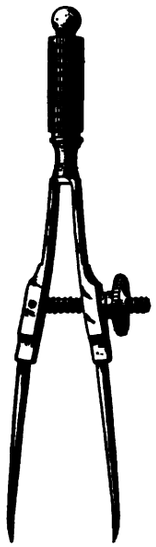

FIG. 53.

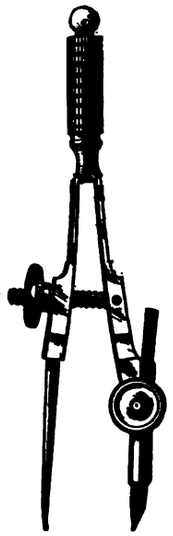

FIG. 54.

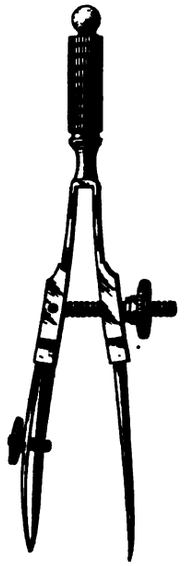

FIG. 55.

wear out rapidly, and renders the adjustment difficult. All these instruments are manipulated by means of a small handle at the top, preferably of cylindrical form, and made of metal very finely milled to give a firm hold.

11. The "spacing divider," as it is often called, Fig. 53, consists merely of two plain points; these should be as sharp as steel can be made, *and kept so;* and capable of being screwed up so that the extremities will meet.

The "bow-pencil," Fig. 54, has one leg formed into a clamp for a Faber instrument lead, exactly like that of the compasses. The tube of this clamp *should not be less than three eighths of an inch long;* and the other leg should extend at least the same distance below the lower end of the tube.

Another most important test is the following: Put into the clamp a lead truly sharpened to a conical point, or, better, a wire of the same size thus tapered, and close the instrument. These two points *should come exactly together;* if they do not, the piece is not worth accepting as a gift, unless on condition that the recipient may in turn present it to a rival. In other words, the axis of the tube should lie in a plane passing through the supporting point (or centre of the circle to be drawn) and the axis of the handles.

The most serious fault is to have the tube inclined to that plane; and the next to that to have the clamp come foul of the opposite leg on closing the instrument. The former renders it difficult to draw a circle at all; the latter renders it impossible to draw the smallest ones: both are very common, but neither is excusable.

To do the best work with this instrument, the lead must be carefully trimmed to a clean *edge*, rounded like the point of the drawing pen, and concave on the inner side as in the figure; it must also be as carefully adjusted so as to lie with this edge tangent to the circle, and to be of just the right length. All of which can best be done with the form of clamp here recommended.

The bow-pen, Fig. 55, has one leg formed into a pen, which is exactly similar in form to the drawing pen, Fig. 52. The peculiar curvature of the outer blade, to which attention was called in (**9**), is most important in this small bow, because when set to a very small radius, the pen cannot be cleaned and refilled easily without opening the legs; and when a large number of such little circles of the same radius are to be drawn, it makes a great difference in time whether this operation must be repeated once in five minutes or once in ten.

The bow-pen should be carefully tested by trial, to see that the plane of the edge of the pen is tangent to the circle; and also to see that when closed the opposite leg shall *touch* the inside of the pen, *and that at the middle of the breadth of the blade.*

The supporting point should project a very little beyond the end of the pen or the pencil, so as just to puncture the surface of the paper: and it should be possible with either pencil or pen to draw a circle of one thirtieth of an inch in diameter, or even less.

12. The form of spring-bow above described is recommended as being the lightest and most convenient. One material feature, affecting the convenience, remains to be noted, viz.: *the adjusting screw is pivoted to the pen or pencil leg, and the thumb-nut bears against the opposite leg.* This is of especial consequence in the smaller sizes, and more important in the bow-pencil than in the bow-pen. But it is far preferable to the contrary arrangement, adopted by many makers. For in that arrangement the thumb-nut is in the way of the pencil, unless the adjusting screw is too high up or the pencil-clamp too low down or too short—and very often all these faults exist at once; and again, in drawing several small circles without lifting the bow from the paper, the instrument being held on the centre by the index-finger resting on the top of the handle, the thumb and middle finger are used in changing the radius; so that if the nut is over the pen or pencil the work is obscured by them.

13. If there be but one set of bows, a very convenient size is one inch and three quarters in length, from the crotch of the spring to the point. If there be two sets, the smaller may be one inch and five eighths, the other two inches, in length. They are to be had much larger than this; but are not to be recommended, as too wide a range makes the adjustment tedious; besides, those larger ones are not suited for very small work, and anything beyond the range of the size first mentioned can readily be drawn with the compasses.

These spring-bows, it is to be observed, may be and often are provided with needle-points: and if there be two sets, the larger ones may advantageously be thus fitted; or at least the ones with the pen and the pencil. The advantage is most obvious in the case of the pen bow, owing to the necessity of some adjustment due to the gradual shortening of the pen by wear. But in respect to the wearing of a hole in the paper when many circles are

drawn about the same centre, the advantage is more fancied than real, if the operator handles his instruments as lightly as he should. And in drawing very small circles the needle-point is rather in the way: but if it be preferred, by all means let the *shouldered* needle-point be chosen, and made precisely like that described in (4). Except of course in the case of the spacing divider, which must have tapered points if it has any.

14. Jointed Bows.—The above are the *essential* instruments; if additional facilities for drawing circles are desired, a jointed bow-pen and bow-pencil, Figs. 56 and 57, may be added,

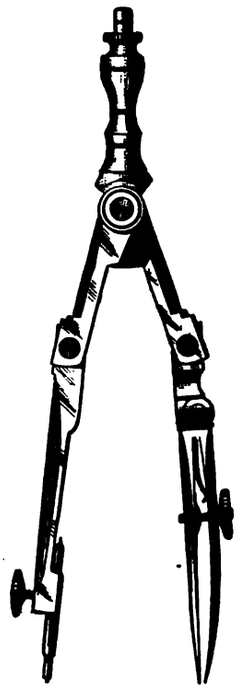

FIG. 56.

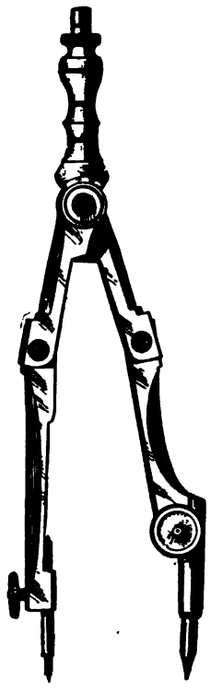

FIG. 57.

and are in many emergencies very useful. They are exactly similar in construction to the compasses, (double-jointed throughout,) with the addition of a handle at the top, a jaw at the lower end of which embraces the main joint of the instrument. Thus these bows are manipulated like those before described, by merely twirling the handle between the thumb and finger.

Bows of this kind should not be more than about two and a half inches in length from the point to the centre of the main joint; for if much longer, they cannot be well controlled by the handle at the top.

And it may be added, that the mere existence of such a handle, for any reason, upon larger compasses or dividers, is a nuisance. It forms a necessary part of the Alteneder joint, which for that very reason is not recommended; it is a very good joint, but not in any particular better than an equally well-made double one, and this excrescence makes it very objectionable for any but the smaller instruments, like those just described.

15. The Beam-compass.—For setting off distances too great for the dividers, and for describing circles of radii beyond the range of the ordinary compasses, the instrument shown in Fig. 58 is used.

This consists essentially of two German silver sockets, *A* and *C*, which slide freely on a wooden bar, or "beam," *B*. The socket *A* has on top a binding screw, *E*, for securing it at any position on the beam; the point of the screw pressing not directly against the wood, but upon a metal tongue fixed inside the socket, which distributes the pressure and protects the beam.

On the bottom of the socket is a cylindrical hub, *O*, drilled to receive the shank of a plain point, *D*, or a needle-point, as the case may be, and fitted with a binding screw to hold the point in place.

The other socket, *C*, also has a clamping screw, *I*, similar to *E*, but on the lower side

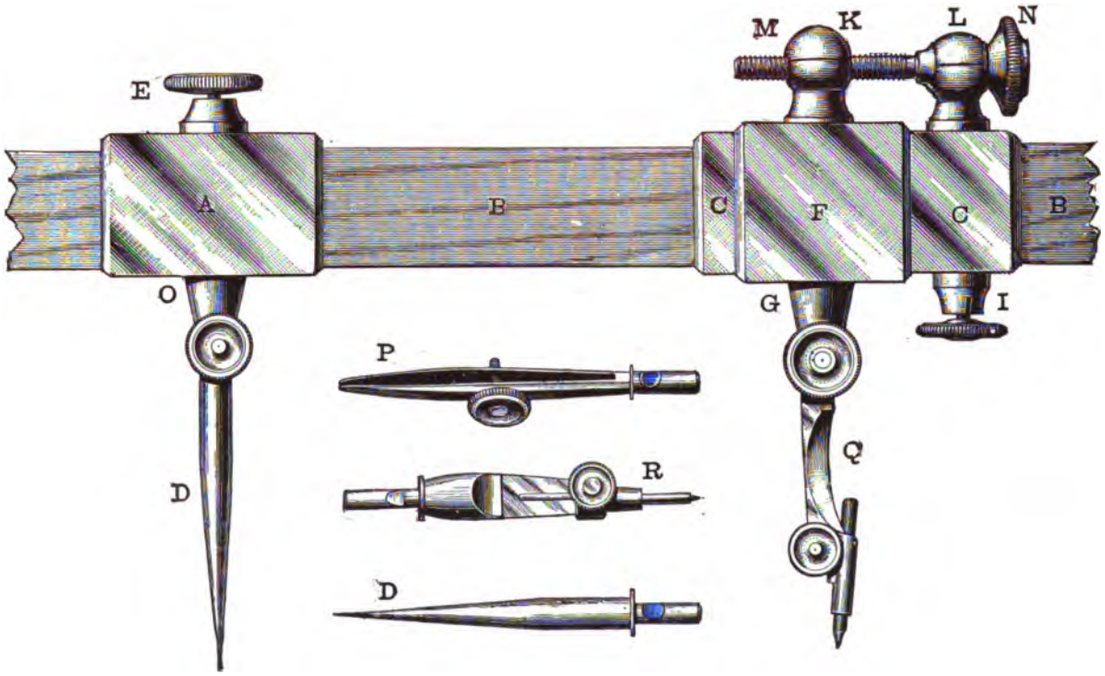

FIG. 58

instead of the upper. It also carries a fixed stud, *L*, which forms a bearing for a journal turned on the prolongation of the screw *M*, operated by the milled head *N*.

The nut for this screw is the stud *K*, fixed on the socket *F*, which is accurately fitted to slide on *C*, and is provided below with a hub, *G*, arranged like *O* for carrying a movable point, a pencil or a pen. Thus when *C* is clamped to the beam after setting the instrument as nearly as may be by the hand, the precise adjustment is completed by turning the milled head *N*.

16. This is recommended as the most convenient form of beam-compass for general use. It will be noted that as *both* sockets slide on the beam, it is easy to keep the instrument in balance, which cannot be done if, as in some forms, one socket is fixed at the end of the bar. And also that, in this arrangement, the whole adjustment can be effected without lifting the instrument off the paper: the beam is naturally supported by the second and third fingers of each hand, and without removing this support, the screws *E*, *I*, and *N* can be manipulated with perfect ease by the thumb and first finger. Thus with a two-foot beam, any number of

circles, varying from four inches to four feet in diameter, can be drawn without moving the needle-point from the centre, and without removing the hands from the most convenient position in handling the instrument.

17. There are two arrangements often found in beam-compasses of different designs, either one of which would be worse than the other, if that were possible. The first consists in having the sockets open at the top, the binding screws being placed on the side; so that they do not require a special beam, but may be clamped on any flat ruler; and they drop off that ruler every time the clamps are loosened to adjust them. The other consists in making the pen or pencil carrier the vertical arm of a bent lever, the fine adjustment being effected by means of a vertical screw acting to raise or lower the horizontal arm: probably the worst adaptation of wrong means to the right end ever contrived by any human being, unless the device of the open socket may share that bad pre-eminence.

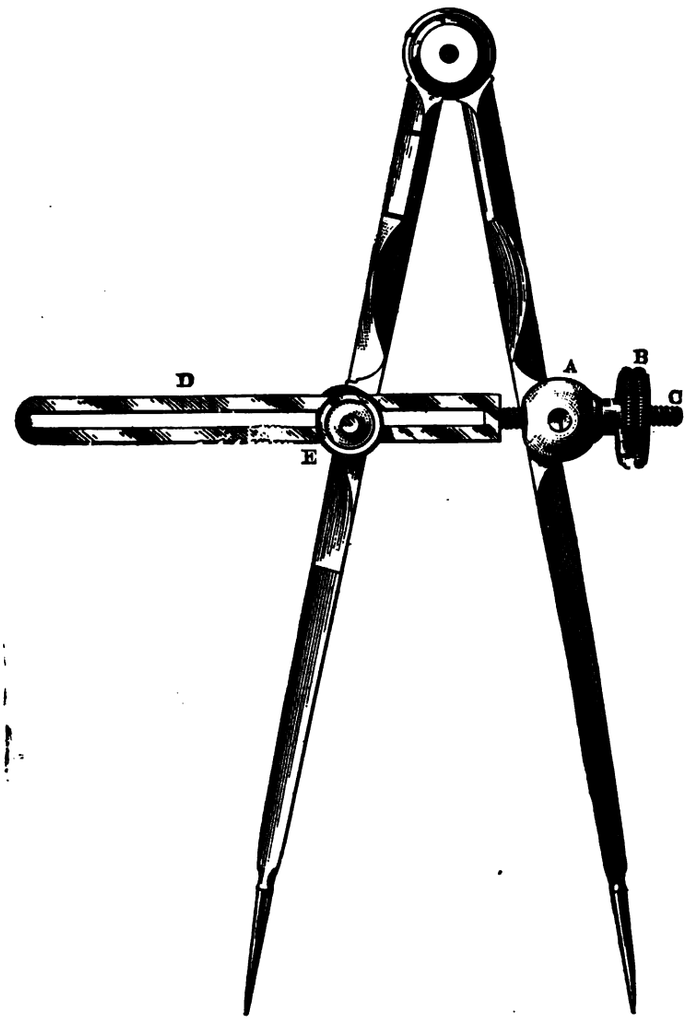

FIG. 59.

18. The "furniture," as it is called, of the beam-compass consists of two plain solid steel points, D, D, used merely in setting off measurements, and especially useful in plotting movement diagrams on a large scale; a shouldered needle-point, R, which should be of liberal diameter in the body, so as to afford a good bearing surface; a pen, P, of the same form as the drawing pens; and a pencil-holder, Q, the construction of the clamp being like that before described.

A beam-compass like that shown in the figure, the sockets being fitted to slide easily on a satin-wood bar of rectangular section, five eighths of an inch wide and five sixteenths thick, is large enough for all ordinary work. In addition to this, one of which the bar is three eighths wide and half as thick, with or without the slow-motion screw for adjusting it, is an exceedingly convenient thing to have; being preferable to the jointed compasses, particularly in inking in, when the circles are so large as to be near the limit of the range of the latter.

19. Dividers with Tangent-screw.—This instrument, Fig. 59, is to be classed among the draughtsman's luxuries. It is not very often wanted, but when the occasion does

come, it is wanted very much: as for instance in laying out a wheel whose number of teeth is 31, or 67, or any large prime. There is in such cases, as every expert knows, no practical escape from the operation of setting the dividers to the chord, and "stepping this distance off" around the pitch circle. And if the pitch is too great for the spacing divider, Fig. 53, the instrument here shown is invaluable.

It consists essentially of a pair of dividers made much heavier than the plain ones, to one leg of which is pivoted the ball *A*, so as to turn freely. An adjusting screw, *C*, is formed on the end of a slotted steel bar, *D*, and passes through the thumb-nut *B*, which is extended into a journal whose bearing is in the ball *A*; "end shake" is prevented by a set-screw with conical point, which enters a triangular groove in the journal. The other leg of the instrument has a hub projecting from its face, upon which the bar *D* rests; and into this hub is tapped a binding screw, *E*, which passes through the slot. When this screw is loosened, the dividers are manipulated like the ordinary ones, and set as nearly as possible to the right measurement; the screw *E* is then tightened, and the adjustment completed by turning the nut *B* in one direction or the other as may be required.

20. By means of this attachment, the dividers can not only be adjusted with the utmost accuracy and facility, but they will stay so: and this last consideration is often very important, as the slightest accident, such as may happen to the most careful operator, either "alters the set" of the common dividers, or, what is almost as bad, leaves it uncertain whether it has done so or not.

The immense superiority of this device to the common and cheaper one of the "hair-spring" and screw is too evident to require demonstration. The hair dividers are not only liable to accidental derangement through a movement of the legs at the joint, but unless the spring is uncommonly stiff, and the manipulator unusually certain of hand, the spacing with it is subject to variations due to springing of the adjustable leg; far more so than the small spacing divider, on account of the greater length.

21. As previously stated, a great many other instruments are often put into the larger cases, and there is a pleasing delusion that they make the outfit more complete. Among these, in addition to the hair dividers, may be mentioned proportional compasses, "wholes and halves," bows and compasses with reversible points, "railroad" or double pens, dotting wheels, metal squares, triangles of small size and unknown angles, sectors, broad ivory scales with the sides covered with lines and figures like those of Gunter, rectangular protractors, three-legged compasses, three-bladed pens, parallel rulers and opisometers.

In this list there is not an item of any value to the mechanical draughtsman, and hardly one of practical use to anybody else; some of the articles are very expensive, and none of them will, by any service rendered, pay interest on the first cost. Probably the one most absurdly overrated is the proportional compass, which is a brazen impostor, and the use of it is a waste of time.

22. The Drawing Board.—The best material for the drawing board is clear, well-seasoned, straight-grained white pine, free from knots and from turpentine. If the board be too large to be made of a single piece, the requisite breadth is made up of two or more pieces by simply matching and gluing the edges, without tongues or grooves.

In order to prevent the board from warping, two battens of hard wood are fitted

into dovetailed grooves across the back; these should be fitted accurately, so as to require to be driven in, but on no account should they be glued in. The object is to allow the board to expand or contract as it will, sliding slightly on the battens, and no fastening must interfere with this freedom. In order to weaken the board transversely, and thus lessen its power to warp, the back is run lengthwise over a circular saw, thus cutting a series of slits half through its thickness, from a half to three quarters of an inch apart, as shown in Fig. 60, which represents a drawing board such as above described.

If the board be a large one, it may advantageously be not only weakened but lightened by planing a series of grooves in the back, instead of merely slitting it; these may be three quarters of an inch wide, and the ribs left between them of the same breadth, making the section of the board appear as shown at *A*. The battens for large boards may also be more easily fitted if made in two pieces, as at *B*, which should be both glued

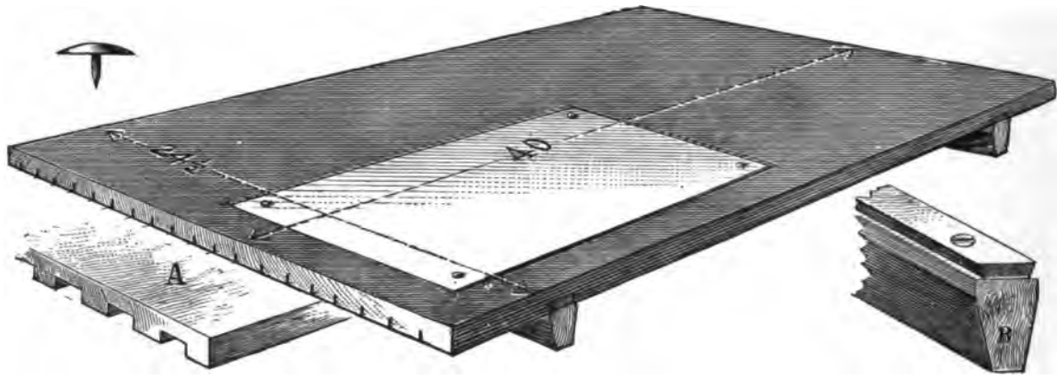

FIG. 60.

and screwed together: the upper strip, which slides into the dovetail groove, should always be of ash, cherry, or similar hard wood, but the lower and larger piece may be of pine. The ends and edges of the drawing board should be *planed* true and smooth, and its upper surface sand-papered. But no oil, paint, varnish, or polish of any kind should be applied to any part of it.

The above is believed to be the best construction possible for a board made entirely of wood: and even if an iron frame were to be used, substantially the same principles should be adhered to in making the wooden centre. This is mentioned here, because it must be admitted that the most minute precision can be attained only by the use of metal straight-edges and squares, including the edges of the drawing board and both stock and blade of the T-square. But for the ordinary purposes of the mechanical draughtsman a sufficient degree of accuracy can be secured by using wood instead of metal.

23. The T-square.—Two forms of this important instrument are shown in Fig. 61, one with a fixed, the other with a movable, blade. In the first the blade is usually secured to the side of the stock by gluing, as well as by the screws shown. But, however it is fastened, let it be noted that it is not let into the stock, or head, but simply laid over it: thus when in use, the upper side of the stock is flush with the face of the paper. This allows the triangle to slide past the edge of the paper, at the left, instead of being arrested by the inside of the stock as when the blade is let into it.

The same construction is adhered to in the other form, the blade in that case being held in any desired position by *two* binding screws. The inner one of these is fixed in the stock, and passes through a hole in the blade, thus serving as the centre of rotation when the milled nut is loosened. The other one has a round head below the stock, and a portion of the neck of the screw is fitted to slide in a circular slot in the stock itself, whose centre is the first screw: it then passes through another hole in the blade and is fitted above with a milled head like the other one. Thus the blade is easily set at any

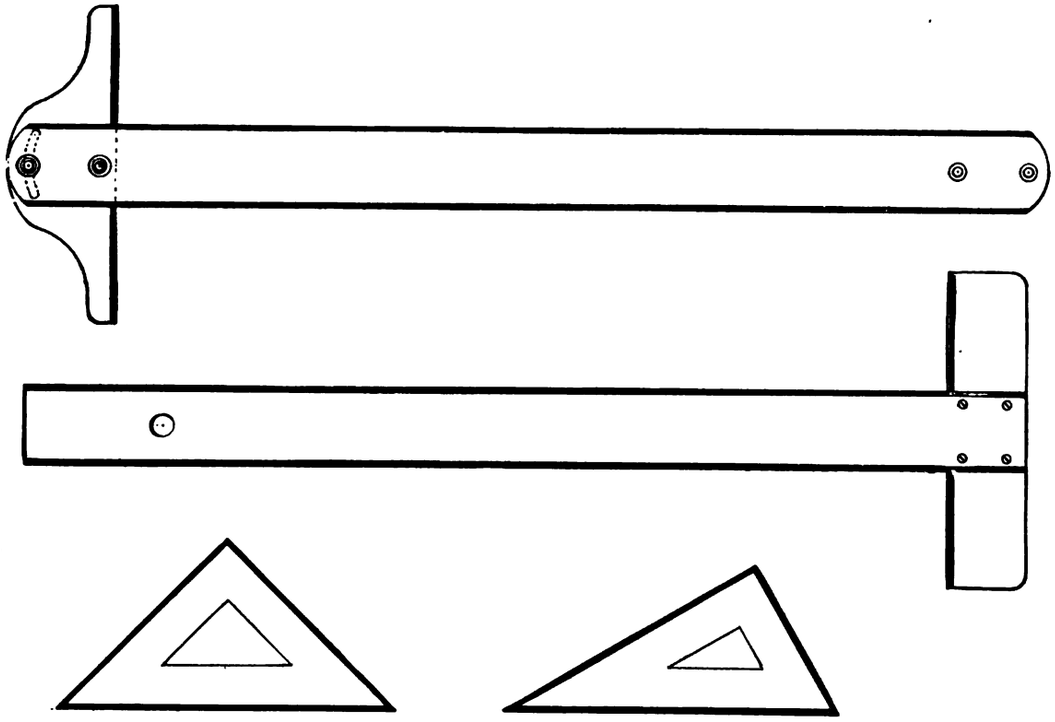

FIG. 61.

angle, and, what is most important, *it can be set firmly;* and this is due to the use of *two screws.* In many styles of "swivelling heads," as they are called, but one screw is used, and the strength of a Samson will not suffice to fix the blade with the requisite firmness. This forms a very excellent square; two correspondingly placed holes for the screws should be made at the other end of the blade, and all these four should be bushed with brass: thus the blade can be reversed in the case of injury to the upper edge, and also detached and used as a simple ruler.

The blade should be made of wood which is fine-grained and hard. If of a single piece, probably satin-wood is equal if not superior to any for large blades, though solid ebony is used for very small ones. But a blade of any size may be made with ebony edges, and such blades are the best of all; the well-defined contrast between the paper and the ruler materially lessens the strain on the eyes, and the grain of the ebony itself is admirably adapted to the purpose. Such are the ones shown in the figure; the body of the blade may in this construction be made of any wood that pleases the fancy;

satin-wood and mahogany are very suitable. The finish that can be given to these, without any application in the nature of varnish, is sufficient for practical uses; though the beauty is enhanced by "French polishing," and also the liability to become soiled by adhering dust is diminished, and they are more readily cleaned. But on no account should any instruments of wood be "finished in oil," as they sometimes are: which is worse than no finish at all. Hard rubber is sometimes used for blades; but unless for what might be called miniature instruments it cannot be recommended, being too flexible and too brittle for those of any size.

24. The dimensions and proportions of the drawing board must of course depend to a great extent upon the nature of the work to be done, as well as on the fancy of the user. The one represented in Fig. 60 is of convenient size for a portable article, to be placed on any table; it is 40 inches in length, 24½ inches wide, and ⅝ inch thick, the battens of ash, one inch wide by one inch and a half deep, placed about three inches from the ends. For larger work larger boards must be used, and somewhat thicker in proportion: these are usually provided with a permanent stand, which should be strong and substantial, what is known as the "saw-buck" pattern being commendable for rigidity, and preferable to the common substitute of two separate trestles.

The size of the T-square should be in due proportion to that of the board, being a little less in length, that it may not overhang and be liable to accidental blows. For such a board as the one mentioned above the blade should be, say, 34 or 36 inches in length, about 2½ inches wide, and a full sixteenth of an inch thick. The head, or stock, which is also faced with ebony, as wearing better against the end of the board than softer woods, should be about 10 inches long, 2½ wide, and five sixteenths of an inch thick: this relates of course to the plain, not the swivelling, form of head, though the latter should be of about the same length. For larger work the square is correspondingly larger and thicker: in which case the edges should be chamfered, because the edge of any ruler is inconvenient and unreliable in use if much more than one sixteenth of an inch thick, (at most it should never exceed one eighth,) since the pencil or pen must touch the *upper* corner only. The thickness of the blade should always be such that it can be lifted from the board easily by means of the stock held in the left hand only; if too thin for this, it is too weak.

25. Tests of Drawing Board and T-square.—The T-square is used by holding the stock against either the left-hand end, or the lower side, of the drawing board; the former position is for drawing horizontal, the latter for drawing vertical, lines. When used in either position, all the lines drawn by it should be straight, and also parallel. The first condition requires the blade of the T-square to be straight; the second requires that both the inside edge of the stock, and the end and edge of the drawing board, should be straight. This part of the problem then consists in the testing of straight-edges; which is done by taking two of them, and applying one to the other, observing carefully whether any light can be seen between them: if this is the case at any position while one slides along the other, it is evidence of a fault. But even if it does not happen, the question is not perfectly settled, because each may be faulty, but the convexity of one may fit the concavity of the other. Both should then be separately tried by a third: if no defects be thus found, the presumption is that all three are correct.

This is the only test that need be applied to the T-square. It is a very common superstition that one with a fixed head is worthless if the stock and blade be not exactly at right angles. In fact this is of no consequence whatever except for the sake of appearance: if it were, the use of a movable blade would be very circumscribed; and it is not easy to see what gave rise to this false idea. Because in using the square, first against the end, then against the side, of the board, the two sets of lines thus drawn should be perpendicular to each other. And this requires simply that the lower left-hand corner of the board shall be *true;* that is, that the left end and lower side shall be at right angles; though the corners of the board are preferably slightly rounded off, as being thus less liable to injury. It therefore makes no difference, if the board has its "working corner" a true right angle, whether the head of the square be thus accurate or not.

Now, in order to test the squareness of this corner of the board, it is necessary first to have a good T-square; with this draw a vertical and a horizontal line, intersecting near the centre; describe a circle about the intersection: if the four parts into which the circumference is cut prove on careful measurement to be equal, the corner of the board is square. If all four corners are true, so much the better; but the one mentioned should be made so in every case, while the others are of less consequence.

26. The Triangles, or Set-squares.—These are among the most serviceable appliances used in drawing, and are seldom out of the hands of the expert. They consist merely of two right-angled triangles, the one having two angles of 45°, the other having one angle of 60° and one of 30°, as shown in Fig. 61. They are to be found in great variety of material and of style; some being made of a single piece of wood, others of hard rubber, some of metal, and they can be had of glass. For ordinary practical use the choice lies between those of hard rubber and those of wood, framed as shown in the figure; those of a single piece of wood are not at all to be relied on, but the framed ones are, if thoroughly seasoned. As in the case of the T-square, the best are those with ebony edges, the main frame being of mahogany or satin-wood.

A pair of triangles, or one triangle and any straight-edge, is the best parallel ruler that can be found. For this particular purpose, it would not matter what the actual angles were; but the facility of drawing short vertical lines by placing a triangle against the T-square without moving the latter from the horizontal position, at once suggests the advisability of having one angle of 90° in each, which also enables the operator to draw two lines perpendicular to each other through any point and in any position. And the frequent recurrence of lines at angles of 30°, 45°, and 60° with the horizontal or with the vertical, in mechanical constructions, is a sufficient reason for the adoption of those values in the triangles for common use; though for special purposes other values may occasionally be required. The draughtsman should have one pair of triangles measuring ten or twelve inches on the longest side; and another pair of six or seven inches will be found very convenient. These if of hard rubber will be about one sixteenth of an inch thick; if framed of wood, somewhat thicker.

27. Tests of Triangles.—To test the right angle, place the T-square horizontally, and draw a vertical line with the triangle, placing its base against the upper edge and its hypothenuse sloping to the left. Then reverse the triangle, making the hypothenuse

slope to the right, but keeping the base in contact with the square. Then a vertical line drawn by the same edge as before, should coincide exactly with the one first drawn.

To test the angles of 45°, draw a vertical and a horizontal line through the centre of a circle whose radius is a little less than the short side of the triangle. Place the T-square horizontally, its upper edge a little below the centre of the circle, and against this edge place the hypothenuse of the triangle. Draw first a radius by one side of the triangle, sloping one way, then slide the instrument along and draw another radius by the other edge, sloping the other way. Each of these radii should bisect exactly the quadrant which it cuts.

Another method is to draw the circle of a diameter a little less than the hypothenuse, divide it into quadrants by the vertical and horizontal line as before; then placing the T-square with its upper edge a little below the lowest point of the circumference, place a short leg of the triangle against it, and draw a diameter sloping one way by the hypothenuse. Then use the other short leg as a base without turning the triangle over, and draw another diameter sloping the other way: these two diameters should also bisect the quadrants, and moreover should coincide exactly with two other diameters similarly drawn, but with the other surface of the triangle in contact with the paper.

To test the angles of 60° and 30°, draw the circle, cut into quadrants by the vertical and horizontal lines, as before; and, applying the short leg of the triangle to the horizontal edge of the T-square, draw a diameter by the hypothenuse. The chords of the arcs thus determined, measured from the extremities of the horizontal diameter, should each be exactly equal to the radius. Still keeping the same surface in contact with the paper, apply the long leg to the T-square and draw another diameter; the chords of the arcs measured from the extremities of this diameter to those of the vertical one should also be exactly equal to the radius. And the same should be true also when the other surface of the triangle is placed on the paper and the same process repeated.

28. Abstractly, of course, the short legs of the 45° triangle ought to be equal to each other, and the shorter leg of the 60° triangle should be one half the hypothenuse; but no reliance can be placed on a test depending upon those properties, for practically it is almost impossible to make the angles rigorously sharp, and quite so to keep them in that condition; which is of no consequence whatever, since a line is never drawn by either side quite to the extremity. But the inclinations of the sides to each other should be as exact as it is possible to have them made; for then these little implements, in connection with the T-square and a true-cornered drawing board, enable the draughtsman with the utmost facility to divide the circle into four, six, eight, or twelve parts as may be desired, and to draw with equal ease the inscribed or circumscribed equilateral triangle, square, hexagon, and octagon.

29. Sweeps, or Irregular Curves.—The mechanical draughtsman frequently has to deal with curves which are not circular. In many cases these can be made up of approximating circular arcs; but in others this expedient cannot conveniently be employed. Even when it can ultimately be used to advantage, it is often much

better to draw the line accurately in pencil through the points which are determined by construction according to the given law of the curve, than to attempt at once to find the circular arcs which can be substituted for it.

For practical purposes, in general work, no mechanical contrivance for drawing curves by continuous motion, such for instance as an elliptograph, is of service to an extent anything like proportionate to its cost. Such contingencies as these are best provided against by the possession of a selection of curved rulers, or *sweeps* as they are technically called. The forms of these should, in general, conform to some mathematical law, according to which the curvature varies with regularity: and

FIG. 62.

the dimensions must be in accordance with the scale of the work in hand. For instance, there are to be had sets of ellipses and of hyperbolas, of varying eccentricities, and parabolas on different scales; and these are in many cases of great use. There are also to be had "French curves," "scrolls," or "universal curves" without number and without value. In these last, the radius of curvature almost always changes abruptly at various points, which destroys their regularity and their utility in drawing curves not similarly characterized.

In Fig. 62 are shown the contours of a number of what are known as the "Copenhagen Ship Curves;" which, though originally intended for the use of naval architects, have, with the addition of one or two logarithmic spirals, been found of most material use in the drawing of machinery: they are here reduced to about one half of the actual size. In a great many cases these are of use in inking in arcs of

circles of a few degrees only in length; especially when these are tangent to two other lines, as much time is saved by using the drawing pen thus guided, instead of adjusting the inking point of the compasses, to say nothing of the greater facility in making the joinings of the lines neat and smooth.

Fig. 63 shows a selection of larger curves from the same set as the others: not merely of greater size, but of greater radii of curvature, or in other words flatter. These in particular have been found of great utility in the laying out of screw-propellers; and are shown on a scale of about one third of the actual size. The very best material

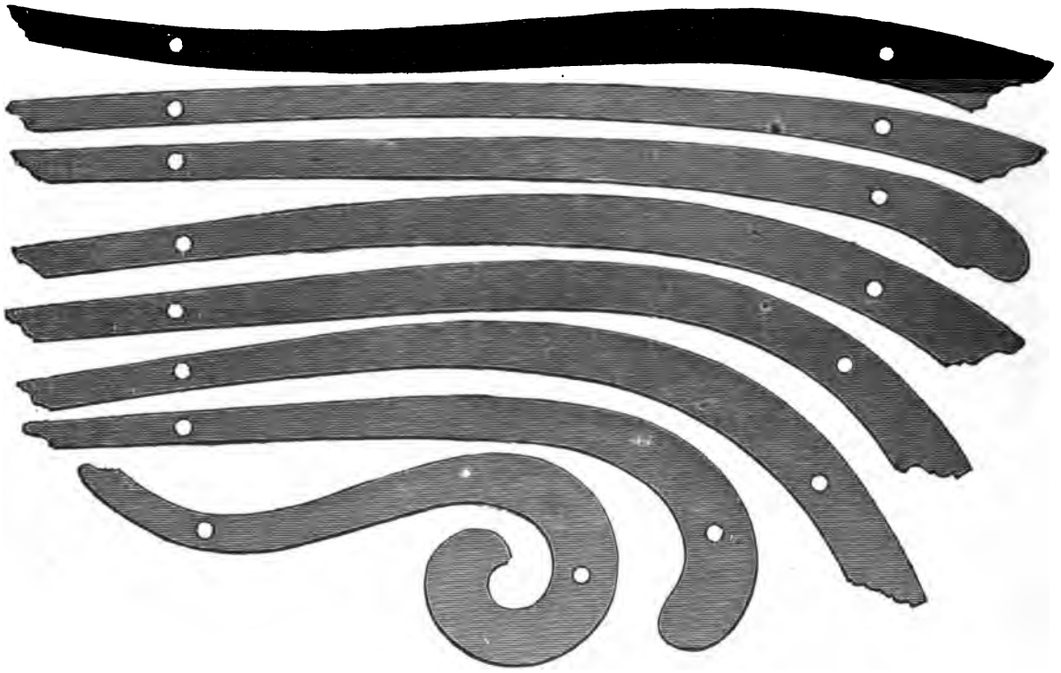

FIG. 63.

for these articles is hard rubber; and all those here shown, as well as the whole set of "Copenhagen" curves, and some of English origin specially adapted for the drawing of the "lines" of vessels, are now to be had of this substance, which is so far superior to wood of any kind as to be in the end much cheaper.

30. The Scale.—The draughtsman's scale is a piece of metal, wood, or ivory, one edge of which is divided into inches, and these again are subdivided into halves, fourths, eighths, and sixteenths. This is called the full-size scale, and is used in laying out drawings of the actual size of the objects represented.

The scale is thus graduated, to correspond with the scales and folding rules used by the workman; this unit and this system being in use throughout the country. The merits, if there are any, of the metric system of measures, and the advantages, real or fancied, of the decimal system of subdivision, are foreign to the question; what is used in the shop must be used in the drawing office, and that definitely settles the matter.

Working drawings are preferably and usually made "full size," unless they would thereby be either too large or too small to be conveniently worked from. In that

case they must be made upon a smaller or a larger scale; that is to say, an inch must be represented by a distance less or greater than an actual inch, and its multiples or submultiples are of course reduced or enlarged in the same proportion: the result being the same as if a full-size drawing were made of a smaller or a larger object.

31. Now, reduced or enlarged drawings can be made with the aid of only the scale above mentioned. If, for instance, a "quarter-size" drawing is wanted, each dimension of the object is divided by four, and the quotient set off with the full-size scale. This, however, is not expeditious, by reason of the amount of mental arithmetic involved; it is very easy to divide by four, but the operation soon becomes monotonous and vexatious by repetition. And this repetition can be wholly avoided by the simple expedient of dividing the scale itself by four at the outset; then with this contracted scale the measurements of the actual dimensions are set off, without dividing them.

Thus, the quarter-size scale is formed by taking three inches to represent one foot; this three-inch space being divided into twelve equal parts, each of them represents one inch; and these are subdivided, like the actual inches on the full-size scale, into halves, fourths, and eighths.

In like manner, *any* distance may be selected to represent a foot, and a similar scale constructed by dividing it into twelve parts, and subdividing them as before. Such scales are usually designated by specifically stating the distance taken to represent one foot; as, for example, "3 inches to the foot," "$1\frac{1}{2}$ inches to the foot," "$\frac{1}{2}$ inch to the foot," etc.; which for brevity's sake are colloquially called the 3-inch scale, the $1\frac{1}{2}$-inch scale, the $\frac{1}{2}$-inch scale, and so on.

32. One of the most convenient forms of scales is shown in Fig. 64. The graduations extend to the very edge, and when the scale lies upon its side they are thus

FIG. 64.

brought into direct contact with the paper, so that measurements may be set off directly, using either a pencil or a needle as may be desired. This is a very important feature; no work can be executed with any reasonable degree of rapidity if the measurements are taken from the scale, and set off, with the dividers or compasses; which should be done only in case of necessity. Again, operations are much facilitated in many cases by laying the scale against the upper edge of the T-square, and thus pushing it along until the edge reaches the line along which distances are to be set off: and the triangular scale lends itself readily to this mode of using it.

The peculiar formation of this instrument allows a number of different scales to be cut upon its various edges. This, to be sure, is not an unmixed advantage, as among so many it is not always easy on the instant to find the one wanted, and were it not for the bulk and the expense, it would perhaps be more convenient in many instances to have but one or two scales, upon one edge only. This would necessitate the use of a number of separate instruments, and the inconvenience thus caused, as well as the increased expense of material, prevent these separate scales from being placed on the market in any form more substantial than that of printed strips of paper. These are

not very durable, but they possess one commendable feature, that of expanding and contracting as the moisture of the air varies, pretty nearly in the same ratio as the paper upon which the drawing is made.

33. These triangular scales are made both of metal and of wood. The former are not solid, but made of drawn brass tubing, with closed ends, nickelled with a dull finish. They are thus very light, and possess the advantages of not being liable to warp, or crack, or chip at the edges; nor are they subject to variations due to moisture like those of wood. On the other hand, they are more trying to the eyes, the graduations not being so strongly in contrast with the surface; and thus far they are not to be had over one foot long.

This is long enough for some purposes, of course; but in general practice in machine drawing, there are so many measurements of more than one foot to be laid off, that a longer one is almost a necessity, if facility and speed are of account.

Those of boxwood are to be had both 18 and 24 inches in length: of these the former is more convenient under average circumstances. It is, besides, of considerably less first cost, and it is much easier to find a perfect one; and when good at the beginning, it is more likely to remain good; for the difficulty of finding a piece of wood which will not check or warp sooner or later, increases very rapidly with the length.

34. The edges of these instruments are usually divided to scales of $\frac{3}{16}$, $\frac{3}{32}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{3}{8}$, $\frac{3}{4}$, $\frac{1}{2}$, 1, $1\frac{1}{2}$, and 3 inches to the foot, and the remaining edge has the full-size scale above mentioned: some have a 4-inch and a 2-inch scale upon one edge, instead of the $\frac{3}{16}$ and $\frac{3}{32}$ scales; but neither one of these four is very frequently made use of.

In selecting, the purchaser should see that the wood is free from veins or streaks, be careful to note that it is as nearly straight as possible (absolute perfection in this respect is hardly to be expected of wood), and above all things that the graduations are *fine* and clean-cut. This last they are almost sure to be if the maker be one of reputation, and there are those whose names are of themselves a guarantee of accuracy; but, on the other hand, scales of this popular form are to be found upon which the lines are very coarsely cut: this is a fatal defect, and all such should be rejected, no matter how good they may be in other particulars; the mere fact of being stamped "U. S. Standard" is not alone sufficient, but the graduations of the smallest scales, such as the $\frac{3}{16}$, $\frac{3}{32}$, $\frac{1}{8}$, and $\frac{1}{4}$, should bear close scrutiny with a magnifying glass without revealing irregularity of divisions or blurring of lines.

MATERIALS AND MISCELLANEOUS ARTICLES.

35. Drawing Paper.—In order to do good work, the draughtsman should be provided with good materials as well as good instruments. For fine work in ink, Whatman's hot-pressed paper is no doubt superior to any other, for making both detail and general drawings of machinery.

It is to be noted that the thickness of this paper varies with the size of the sheet; and the size known as "double elephant" (27 by 40 inches) has a body and substance peculiarly well adapted for these purposes. It may also be stated that this is as large a sheet as ought to be used, unless for very particular reasons. Anything larger than this is inconvenient to handle as a working drawing in the shop; and with a judicious se-

lection of the scales, it is large enough for the details of the most massive machinery. Occasions will arise, as in making plans of vessels, etc., in which these dimensions must be exceeded; but it is usually in length only, a wider drawing being seldom called for.

Where drawings are to be at once sent into the shop and worked from, without tracing, a cheaper paper may be desired. In this case the article known as "Duplex" paper, a Manila paper of a fine creamy tint, serves an excellent purpose. It takes ink fairly well, and for drawing in pencil only, is better than Whatman's; it is to be had of a size very nearly the same as the double elephant.

36. But of whatever make or quality, the paper should be procured in sheets, and *kept flat*, if it is expected to do even tolerable work.

With a mistaken idea of economy, paper is sometimes procured in huge rolls, and cut off as required. If every piece is "damp-stretched" before using, this may answer; but that costs more in time than is saved in the purchase. If, on the other hand, it is merely pinned down as usual, no one can draw upon it as well or as rapidly as he can upon a flat sheet lying smoothly on the board.

The best course is to procure a considerable quantity at a time; if it must be rolled for transportation, let the roll be as large as possible, and as soon as may be, put the whole into a drawer of suitable size, that the weight may act to make it flat again and keep it so. The larger the stock laid in, the better; for whatever the reason may be, good paper improves by age.

37. It seems not to be as generally known as it might be, that for many purposes common writing paper is admirably adapted. Not, to be sure, for making working drawings; but for fine diagrams, and for illustrative drawings, it is perhaps better than any other. The best is the heaviest linen "ledger" paper, which has not only a surface upon which the finest ink lines can be drawn, but sufficient body to permit erasures to be made, still leaving the paper in condition to take the ink without spreading. And thinner writing papers answer exceedingly well for making tracings.

38. Pencils.—It is universally conceded that in all the essential qualities of a good drawing pencil, those made by Faber are unsurpassed. They are to be had of different degrees of excellence as well as of hardness; the "Siberian" are the best. Those marked HHHH are, as regards hardness, most suitable for general use, as if softer, they do not make a fine enough line nor keep long enough in good trim, and if harder, the lines are not so easily erased as is desirable. But for making the very finest work, where there is reasonable certainty that little if any erasing will be necessary, the HHHHHH grade may be used to good advantage.

And this last grade should always be the one chosen for the "instrument leads," already mentioned in connection with the compasses and pencil bows: as there is, apparently, a difference between the gradings of these leads and of those used in the pencils, and these will be found none too hard.

39. Rubber, Ink Eraser, etc.—The rubber for erasing pencil marks should effect that object without soiling the paper; which neither the pure gum (or virgin rubber) nor the black rubber will do. Neither ought the rubber itself to become soiled in the operation; the best is that known as "velvet" rubber, which has some substance incor-

porated with it of such nature that the whole wears off quite rapidly in use, the acting surface remaining clean and fresh.

For erasing ink lines, Faber's "ink eraser" is the best article to use. The use of a knife or other steel instrument should be sparingly indulged in; the edge should be very keen, and the convex portion only should be applied to the paper, so as to *scrape* its surface, and that very lightly: the use of the point of a knife to *scratch* out a line is a barbarism. The ink eraser recommended is similar to the velvet rubber, with a larger admixture of pumice stone, which, used without sufficient force or speed to heat the paper, removes the ink and polishes the surface: which if then rubbed lightly with an ivory paper folder, will be in good condition to receive ink again. Thus with due care, corrections and alterations can be made so neatly as to escape any but the closest scrutiny.

For removing light marks of the pencil, and for cleaning the paper if dusty or otherwise soiled, a very useful article is now furnished, called rubber sponge. It is most excellent when new, but in some way hardens, and gradually becomes useless, with age. Equally good for the same purpose is the crumb of stale wheat bread; it should be broken into small bits and well rubbed, or rolled, into the surface of the paper, thus forming numberless little pellets, to which the dust adheres.

40. Ink.—Ordinary writing ink is wholly unsuitable for mechanical drawing; it rapidly corrodes the pens, and acts chemically upon the paper, making neat erasure almost impossible. For this purpose, then, India ink alone is used; it consists wholly of carbon and some adhesive substance, so that it merely lies on the surface of the paper without "biting in."

The best is of Chinese manufacture, and comes in sticks or cakes of various sizes and forms; this is to be simply rubbed up with water to any desired density. This labor of preparation, slight as it is, is to some persons a great bugbear; and in response to their demands various "liquid India inks" are offered for sale; the bottles, when properly cleaned, are good: which is more than can be said of the contents.

The Chinese inks vary greatly in quality and in price; but it does not always happen that the most expensive is the best. That for line drawings should be comparatively soft, while that to be used for tinting with the brush should be quite hard; but both must be free from grit. In selecting, wet the end of the finger, and rub the ink upon it; that for line work only should in a very few seconds produce a dense black spot, and without any rough or gritty feeling; when dry the spot should have a brilliant lustre, and a dull or cloudy appearance should cause it to be rejected. It may also be noted that the better grades of this ink have, when wet, an odor of musk.

Further, the ink should be tested as to its adhesive power. Draw a broad black line with it, wait until perfectly dry, then apply the rubber vigorously, as if erasing pencil marks. The brilliance of the line may be impaired, but it should remain black and continuous; if it does not, the ink lacks adhesiveness, and is not suited for the purpose.

41. The preceding relates to black ink, which forms a perfect emulsion, and deposits no sediment, merely becoming more viscid as it evaporates. There are also Chinese inks of different colors, but they cannot be recommended, as the coloring matters, though very brilliant, are also very heavy, and do not remain well in suspension. It is therefore

quite difficult to keep the same tone or shade in drawing a number of lines consecutively. For making lines in color, then, the draughtsman cannot do better than to use the cakes of water colors furnished for artists. Preference should be given to those which are most soluble, such as Prussian Blue, Carmine, Scarlet Lake, Indian Yellow, etc.: they are used exactly like the India ink; and like it are not corrosive, which all the colored writing fluids are, and they should not be used with instruments of any value.

42. In preparing the ink for tinting with the brush, the stick should never be dipped into the water, but merely rubbed upon the wetted finger, which again is rubbed upon the bottom of the saucer of water. This is for the purpose of preventing any speck or flake of the solid ink, which is quite friable, from eventually lodging in the brush. It also serves a good purpose in avoiding the immersion of the stick of ink, which becoming soaked and soft, is still more apt to crack and scale off. And there is no doubt that even for line work, the above is the *best* process. But it is undeniably tedious; and it is not absolutely necessary to the execution of even the finest work. For this purpose it is admissible to rub the ink directly in the water; but the solution, or emulsion, should afterward be carefully rubbed with the finger until it is certain that there are no bits of solid ink remaining, for if one of these gets into the pen, as it is tolerably sure to do, it will be found that no time has been gained by neglecting the precaution here insisted on. And dust is nearly as bad; so that the saucer should be kept covered after the ink is mixed: the saucers which come in nests, each being a cover to the one below, are very convenient, as are also those provided with glass plate covers.

Neither the India ink nor the colors should be wetted more than absolutely necessary in mixing, and they should be wiped dry with soft paper, at once, to prevent the absorption of water, which tends to disintegrate them.

The blades of the drawing pen being moistened by breathing between them, the ink is introduced by means of a common steel writing pen which has not been used with any writing fluid, and should be kept for this purpose exclusively.

The ink will look black in the saucer, when in fact it is not as dense as it should be. The test is to draw a broad black line with one stroke of the drawing pen: this when dry should be absolutely black; if it be grayish or brownish, the ink is not thick enough. It will of course become thicker by evaporation as the work progresses; hence care should be taken to prepare a comparatively large quantity at the outset; in diluting it afterward if necessary, water should be added a few drops at a time, and the whole rubbed with the finger after each addition. And the same process should be adopted in again mixing ink which has dried in the saucer when set aside, which is perfectly good for line work; but for tinting the saucer should be washed out and fresh ink prepared.

43. Drawing Pins, or Thumb-tacks.—For all ordinary purposes, particularly for working drawings, the paper should merely be secured to the board by a "drawing-pin" at each corner, as shown in Fig. 60: being placed as near to the lower left-hand corner as possible. As a matter of course, the paper will expand and contract to some extent on account of variations in the moisture of the air: for which an allowance dictated by ex-

perience must be made in using the scale, unless the latter itself be of paper. But the errors due to this cause are less than those which arise when a "stretched" sheet is cut loose; upon which the paper contracts, and that not only to a variable and uncertain extent, but not always evenly; so that lines which ought to be straight are sometimes quite the reverse.

The form of these drawing pins is shown in Fig. 60: the heads are slightly *convex*, not bevelled, and the pins are *cylindrical* with tapered points; and not wholly conical. They are so inexpensive that none but the best should be used; these are made by *screwing* a steel pin into a German-silver head: cheaper ones have the pin riveted into the head, and the riveting if slight may yield under the pressure of the thumb, causing serious injury.

44. Damp-stretching.—For making line-drawings in the nature of pictures, it is sometimes desirable to have the sheet stretched, as it undoubtedly gives a smoother surface than can be obtained in any other way; and for tinting, if the surface be of any size, it is indispensable. The operation of "damp-stretching" consists essentially in wetting the back of the paper and gluing or pasting down the edges while thus expanded; but to do this neatly requires some little care and skill: attention to the following directions will, however, be likely to ensure success.

1. Chamfer the edges. To do this, lay the sheet, face up, on the board, and with a ruler and a very sharp knife, cut just through the surface, about a quarter of an inch from each edge. The strips thus partially severed are now to be *torn* off, taking care to pull downward and away from the sheet. Thus the edges will be left sharp, thin, and at the back slightly roughened, which will cause the paste to hold better.

2. The paper still lying face up, fold over each edge, say three eighths of an inch for a double elephant sheet, and for different sizes in proportion.

3. Turn the paper face downward, and wet the back thoroughly, leaving the folded edges dry. Water may be poured on the middle of the sheet, but toward the corners the sponge must be used, in order to have all parts equally wet. Allow the paper to soak until the whole is perfectly limp; then take off the surface water with the sponge.

4. Turn the paper again face upward, lay a sheet of thin soft wrapping paper upon it, and rub with an old linen handkerchief *from the centre outward*, with considerable force, to press out the wrinkles. Lay strips of paper an inch wide under the folded edges, to prevent accidental smearing of paste upon the face of the sheet.

5. The best adhesive preparation is *dextrine;* mixed up with water, not into a liquid, but into a thick glutinous mass; with which the edges are to be well covered. If it should happen to become too dry in any part before the edge is turned down and secured, it is only necessary to wet it slightly; and after the paper is cut loose, the remaining edges can be readily removed and the board cleaned, by liberal sponging.

6. Apply the dextrine first to only about one third the length of the sheet, *in the middle of one side.* Turn down that portion, lay a strip of clean paper over it, and rub hard with an ivory paper folder or something similar; it is well also to put a thumb-tack at each end of the part thus treated. Then proceed in like manner with *the middle part of the opposite side:* take next the middle of one end, then the part opposite to that;

and leave the corners to the last, completing them in any order that is most convenient.

7. In removing a stretched sheet from the board, cut first *one side*, and next *one end*. If two opposite sides or ends are cut in succession, the sheet is very likely to have a corner torn off by the contraction of the paper when the first transverse cut is made.

45. Mounted Paper.—It is rarely that mechanical drawings are subjected to usage requiring them to be "mounted" on linen, as maps frequently are. But no map or drawing should be mounted on linen after it is made; for that operation involves a second wetting, with a nearly absolute certainty of distortion upon drying. Ready-mounted paper should be used; this may be stretched as above explained, that is by dampening, and then fixing the edges to the board. But let it be observed, that in this case the *face* must be wetted, as the application of water to the back would loosen the linen and ruin the sheet; also that, owing to the weight of the material, glue should be used instead of dextrine. If the greatest accuracy in the finished work is required, the sheet should be stretched only for the purpose of making it smooth, and it then should be cut loose, and merely fastened with large thumb-tacks while the drawing is in progress.

46. Tracing Cloth.—This is used for making copies of drawings which may be employed either to work from directly, or for reproducing the original by the "blue-print" or other heliographic process. In the latter case *all* the lines should be black; in the former, colors may be used for centre lines and to distinguish one material from another. A good coat of clear shellac varnish should be applied before the tracing is sent into the shop.

In selection, Hobson's choice is substantially that now offered the purchaser; the manufacture being apparently a monopoly, the result being the production of but one quality, which might perhaps be called good were it not immeasurably inferior to that formerly furnished; an article fifty per cent better, though no higher in price, than any now to be had.

By reason of this depreciation, there is great liability to the mishap of having the ink strike through the coating and spread in the meshes of the cloth; the ink must be pretty thick, the pen in good condition and lightly used; but no precaution will ensure the operator against this most annoying accident, which never ought to occur.

47. Tracing Paper.—Of this article there are fortunately several varieties to be found, and most of them of excellent quality; it is to be had in sheets of various sizes, and also in rolls. And it is to be said that its perfect flexibility prevents any injurious effect from keeping it rolled, even on a small roller; when spread over the drawing it will lie flat, without curling.

Some of the tracing papers are white, others of a yellow tint; so far as the quality, and the ease of drawing upon them, are concerned, there seems to be little difference; but the former are to be preferred if it be intended to make blue-prints.

Among the best and strongest of these varieties are those known as "parchment tracing-paper," and "parchment process tracing-paper;" the latter is remarkably heavy and tough, the former thinner but of similar toughness, and both are exceedingly smooth and fine in surface. There is, however, one variety, known as "vegetable parchment," against which the purchaser should be warned. It is unusually clear,—so

clear indeed that it is not easy to tell which lines have been traced and which have not; but it does not take ink perfectly, and it expands and contracts so much with apparently no provocation at all, that it is next to impossible to make a tracing which tallies with the original.

As before mentioned, some of the thin writing papers are excellent for making small tracings. And what is known as "bond paper" can also be used to good advantage, if the lines of the original are not too fine—it is not so transparent as the regular tracing papers, but is much stronger and more durable.

ON THE USE AND CARE OF INSTRUMENTS.

48. The Compasses.—In striking a circle with a pair of compasses, the uninstructed novice is very apt to take hold of the instruments by the legs, thinking that they are thus more securely held. This habit once formed is difficult to abandon, like other bad habits; at the very beginning, therefore, the tyro should accustom himself to the correct manipulation, and to handle the compasses by the joint alone, using only the thumb and the first two fingers.

Begin the circle at the lowest point, holding the joint of the compasses between the thumb and the middle finger, the index finger resting lightly against the left side of the joint. Turn the compasses *with* the clock, describing the left half of the circumference by rolling the joint between the thumb and second finger; that finger can go no farther, but its place is then easily and naturally taken by the first finger, and the joint is rolled between it and the thumb until the circle is completed, by one continuous motion. This requires a little practice, but the trick of it once acquired is never forgotten, and the instrument is at all times under perfect control, with no danger of altering the radius. The action will be readily understood by the aid of Figs. 65 and 66. In setting the compasses to draw a circle of given diameter, it is not enough simply to open the legs to the required radius, for it seldom happens that this can be done with exactness; two short arcs should be struck, on opposite sides of the centre, and the scale applied to see that the *diameter* is correct: this should not be done on the drawing, but on a separate piece of paper.

In order to make a line of uniform thickness, the pen must be used with uniform pressure; and this should be the lightest practicable. If the pen is *new*, that is, just sharpened, the merest touch is sufficient, so that instead of bearing down, the operator should rather support part of the weight of the compasses.

The fact that a variation in the pressure makes a difference in the breadth of the mark with either pencil or pen, is made use of in putting in shadow lines. The marking point is put in motion before touching the paper, the pressure gradually increased towards the part where the greatest thickness of line is required, then gradually diminished, and taken off the paper while still in motion; the whole action being analogous to the use of a writing pen in shading letters and flourishes.

The two legs of the compasses should always be kept in a *vertical plane*, and the marking point as well as the needle-point, perpendicular to the paper.

Some draughtsmen have a vicious way of holding the compasses so that both legs

lean over, in the direction in which they are moving: an excellent way to ream out a conical hole at the centre of the circle, and to spoil the pen at the same time.

94. The Dividers.—These should be handled in the same manner as the compasses;

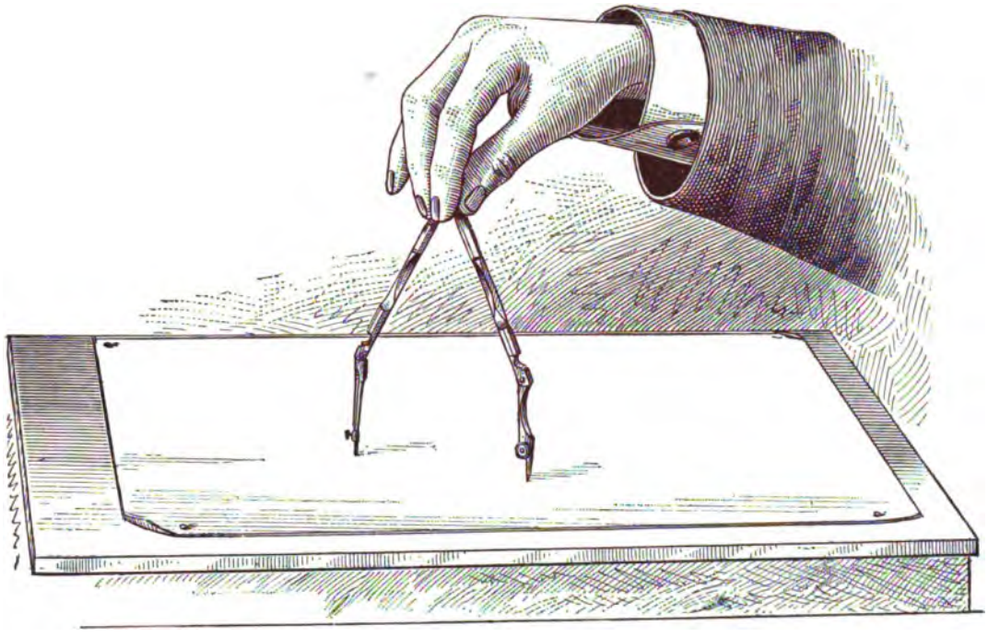

FIG. 65.

that is to say, they should be held by the joint only, and not by the legs; which last is not only awkward to a degree, but is very liable to derange the adjustment. In "stepping off" a measurement repeatedly along a line, or around a circle, they should not be

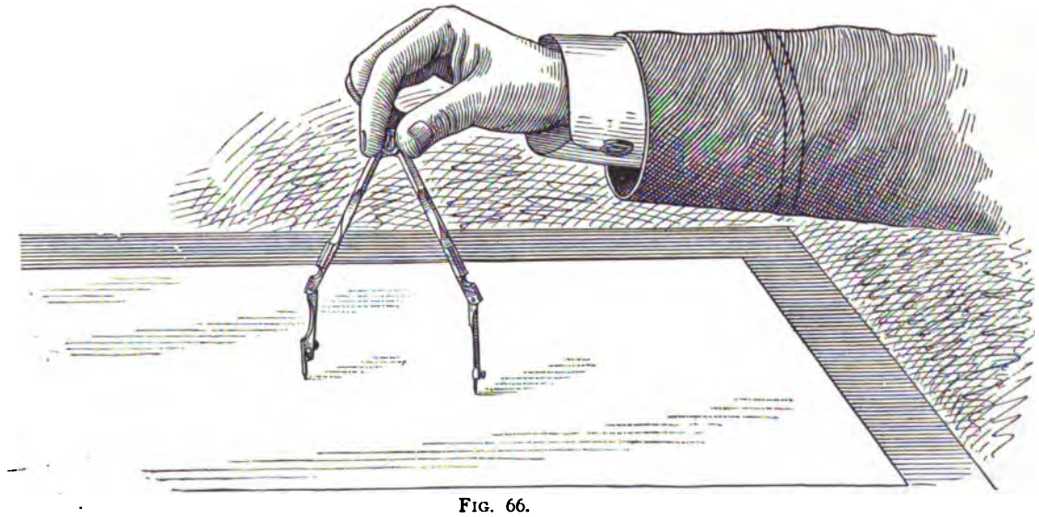

FIG. 66.

lifted entirely off the paper, but first one point and then the other is taken as a centre, and the instrument is manipulated as if describing a series of semicircles, the rotations being alternately with and against the clock. Thus it is never required to shift the di-

Another and in general a preferable method is to set the *hypothenuse* of the movable triangle by the given line, one leg being in contact with the fixed one: the former is then shifted so as to bring the other leg in contact, and the perpendicular drawn by the hypothenuse, which will now be at right angles to its first position.

53. It is to be particularly observed, that in "setting" a triangle, T-square, or any ruler by a given line, no attempt is made to bring its edge into actual *coincidence* with that line; it is to be so placed that the given line could be redrawn, or produced if required, by the edge in question; which will therefore be separated from the line itself by a small, uniformly wide, space of white paper, technically called "daylight." So also in setting a ruler to draw a line through two given points, through a given point in a given direction, through a given point and tangent to a given curve, tangent to two curves, or tangent to a given curve and in a given direction: in all these cases the accuracy of the adjustment depends upon the certainty with which the eye can judge of the equality of the minute distances measuring the "daylight" at different points, and this certainty is practically absolute.

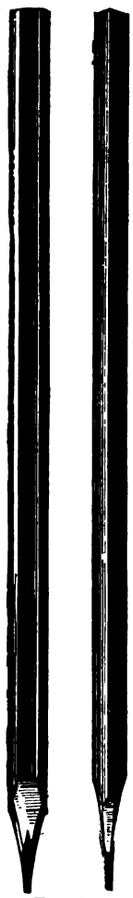

FIG. 68.

A single illustration will suffice to show the utility of a pair of reliable triangles. Let it be required to draw a right line tangent to two given circles, and to find the points of contact. This can be done by a geometrical process, but much more readily thus: taking the two triangles together, set the hypothenuse of one to draw the tangent, hold the other one still, turn the first so as to bring the other leg in contact, then slide it along and draw lines by its hypothenuse through the two centres to cut the circumferences: the result will be practically more to be depended on than that of a geometrical construction.

54. The Curved Rulers.—These are used, as has been explained, for drawing curves through points determined by construction. In using them, they are "set" so that some part of the ruler in hand shall enable the operator to draw a portion of his line; the edge not passing through, but being equidistant from, so many of the given points as may be.

Now in order to make sure not only of a good joining, but of proper alignment in producing the curve, this precaution must be carefully observed; that in setting the new sweep, it must be so adjusted as to agree with a part of the line already drawn. Otherwise, the eye is very likely to be deceived, and the new part of the line is apt not to be tangent to the first part; the result being painfully evident in the form of a "hump" or "broken back."

55. The Pencil.—For the operations of mechanical drawing, the pencil should be sharpened, not to a round point, but to an edge; not a square edge like that of a chisel, but rather like a duck's bill; rounded off at the end, as shown in Fig. 68; and the flat side is held against the ruler, precisely as the drawing pen is held.

By trimming the pencil in this way, fine clean lines can be drawn with it much longer than if it were cut to a conical point. Some make use of fine sand or emery paper to bring the pencil to an edge; others prefer a file; but a sharp

knife is better than either. The instrument leads are trimmed in a similar manner, as has already been stated; and so set in the clamp as to have the edge run in the direction of the circumference to be drawn.

The draughtsman should be as sparing as possible in the use of the pencil; the lines should be fine, because the ink does not run as well if there be much superfluous pencil lead on the surface of the paper; and the pencil line should not extend beyond the limit of the proposed ink line if it can be avoided.

It is just as easy to leave out a line as to rub it out, nay, easier; and no unnecessary ones should be even pencilled in. Lines that are to be dotted in ink ought always to be dotted in pencil, lest the fact that they are to be dotted be forgotten when the pen is taken in hand. In short, the pencil drawing should look as nearly like the ink drawing as possible; the advantage is readily seen when it is considered that if time presses, tracings must often be made from the pencil drawing direct. If this be intended, the pencilling should be heavier than if the sheet is to be finished in ink.

56. The Scale.—The scale should never be used as a ruler, for which it is neither intended nor well fitted. It should be used only for setting off measurements on the drawing, and for measuring distances. Its utility for either purpose depends upon the perfection of its edges, and the accuracy and fineness of the graduation; and nothing should be done which tends to injure either.

In either measuring or setting off distances, the scale should be applied directly to the drawing, and in the latter operation, the points should be marked with either a needle, or a finely sharpened pencil, which latter is in general the better instrument.

The compasses and dividers should be applied to the surface of the scale only in urgent cases: in setting the compasses to a radius, the best way is to lay the scale on the paper and adjust the instrument by the edge, thus avoiding the scratching and defacing of the graduations by the needle-point.

In setting off a number of consecutive measurements along a line, as A, B, C, D, etc., it is perhaps more *convenient* to set off first A, then to move the scale and lay off B, then from the third point to set off C, and so on, since in each case only one distance requires attention. But since there is a probable error in each independent operation, and at least an even chance that these errors will accumulate instead of balancing, this is not an advisable method.

The proper way is to keep the scale stationary; then from zero set off in succession the distances A, $A+B$, $A+B+C$, $A+B+C+D$, and so on to the end, or as far as the length of the scale will permit. In this way it is ensured that the whole as laid off will be equal to the sum of all its parts, which it might not prove to be if the first mode of operation were adopted.

57. General Remarks.—It is hardly necessary to suggest to any one, certainly not to him who has made his outfit pay for itself, that good care of all instruments will be found profitable: neglect and improper usage will soon ruin a set which if treated as it should be would do good service for two generations of draughtsmen. It is not enough to see that the pens are always clean and in good order; the needle-points and the points of the dividers are necessarily extremely sharp, and therefore the more likely to

be broken by careless handling. If this happens, no attempt should be made to use them until they are resharpened: but it is better to prevent it. When not in use, the instruments should be replaced in the case, if there be one; if not, a piece of cork is a good protection to the points of dividers and the blades of pens.

In order to do good work, the paper must be kept clean: and there should be always at hand either a soft feather duster, an old linen handkerchief, or the like, with which to remove not only dust, but more particularly the *detritus* left after using the rubber: a particle of either in the pen is sure to cause annoyance, if not to spoil the lines.

But in spite of all care, dust or dirt will eventually adhere to the wooden instruments; if this be allowed to go on to any great extent, it will be impossible to keep the paper from being soiled by the sliding over it of the squares and triangles, though they be ever so carefully brushed. It is well to know, then, that this closely adhering dirt, as also ink-stains and the like, may be removed without injuring the articles in the least by vigorous rubbing with a cloth *slightly* dampened: much water is not good, but the result of using a little in this way is surprising to one who has not seen it tried.

APPENDIX.

THE proportions of bolts, nuts, threads, and bolt-heads, according to the Sellers system, adopted as the U. S. standard, are given in the first of the annexed tables.

In this system the thread of the screw is of the V form, with its surfaces inclined at an angle of 60°, and with the angles cut off at the top and filled in at the bottom to the extent of one eighth of the depth of the V-thread each, so that the depth of the thread is three fourths that of the full V form. Or it may be defined by saying that the breadth of the flat, at the top of the thread and also at the bottom of the groove, is one eighth of the pitch.

Let D = outside diameter of belt,

P = pitch of thread.

Then the other dimensions given in the tables are calculated by the following formulæ, viz.:

$P = 0.24\sqrt{D + 0.625} - 0.175$;

Number of threads per inch, ... $\frac{1}{P}$;

Depth of thread, ... $0.65P$;

Diameter inside of thread, ... $D - 1.3P$;

Short diameter of head and nut, hexagonal or square, . . $\frac{3}{2}D + \frac{1}{8}''$;

Depth of nut, ... D;

Depth of head, ... $\frac{3}{4}D + \frac{1}{16}''$.

The number of threads per inch, as determined by these formulæ, is in practice so far modified as to use the nearest convenient aliquot part of a unit.

U. S. STANDARD SYSTEM.

Diameter of Bolt.	Threads per Inch.	Dimensions of Nut.				Dimensions of Head.			
		Long Diameter.		Short Diameter.	Depth.	Long Diameter.		Short Diameter.	Depth.
		Hexagonal.	Square.			Hexagonal.	Square.		
1/4	20	5/16	11/32	1/4	1/4	5/16	11/32	1/4	1/4
5/16	18	11/16	27/32	11/32	5/16	11/16	27/32	11/32	11/32
3/8	16	13/16	31/32	11/16	3/8	13/16	31/32	11/16	11/16
7/16	14	15/16	1 5/32	13/32	7/16	15/16	1 5/32	13/32	13/32
1/2	13	1	1 1/2	7/8	1/2	1	1 1/2	7/8	7/16
9/16	12	1 1/8	1 9/32	31/32	9/16	1 1/8	1 9/32	31/32	31/32
5/8	11	1 7/32	1 1/2	1 1/16	5/8	1 7/32	1 1/2	1 1/16	17/32
3/4	10	1 7/16	1 3/4	1 1/4	3/4	1 7/16	1 3/4	1 1/4	3/4
7/8	9	1 31/32	2 1/32	1 7/16	7/8	1 31/32	2 1/32	1 7/16	29/32

U. S. STANDARD SYSTEM—*Continued.*

Diameter of Bolt.	Threads per Inch.	Dimensions of Nut.				Dimensions of Head.			
		Long Diameter.		Short Diameter.	Depth.	Long Diameter.		Short Diameter.	Depth.
		Hexagonal.	Square.			Hexagonal.	Square.		
1	8	1 7/8	2 5/16	1 1/8	1	1 7/8	2 5/16	1 1/8	1 1/16
1 1/8	7	2 1/32	2 5/16	1 1/16	1 1/8	2 1/32	2 5/16	1 1/16	1 1/16
1 1/4	7	2 5/16	2 13/16	2	1 1/4	2 5/16	2 13/16	2	1
1 3/8	6	2 17/32	3 3/32	2 3/16	1 3/8	2 17/32	3 3/32	2 3/16	1 3/16
1 1/2	6	2 3/4	3 11/32	2 3/8	1 1/2	2 3/4	3 11/32	2 3/8	1 5/16
1 5/8	5 1/2	2 31/32	3 3/8	2 5/16	1 5/8	2 31/32	3 3/8	2 5/16	1 3/8
1 3/4	5	3 5/16	3 7/8	2 1/2	1 3/4	3 5/16	3 7/8	2 1/2	1 1/2
1 7/8	5	3 11/32	4 3/32	2 11/16	1 7/8	3 11/32	4 3/32	2 11/16	1 11/16
2	4 1/2	3 11/32	4 11/32	3 1/4	2	3 11/32	4 11/32	3 1/4	1 5/16
2 1/4	4 1/2	4 1/32	4 11/16	3 1/4	2 1/4	4 1/32	4 11/16	3 1/4	1 1/2
2 1/2	4	4 15/32	5 15/32	3 7/8	2 1/2	4 15/32	5 15/32	3 7/8	1 11/16
2 3/4	4	4 29/32	6	4 1/4	2 3/4	4 29/32	6	4 1/4	2 1/4
3	3 1/2	5 11/32	6 17/32	4 5/8	3	5 11/32	6 17/32	4 5/8	2 5/16
3 1/4	3 1/2	5 25/32	7 1/16	5	3 1/4	5 25/32	7 1/16	5	2 1/2
3 1/2	3 1/2	6 7/32	7 13/32	5 3/8	3 1/2	6 7/32	7 13/32	5 3/8	2 11/16
3 3/4	3	6 5/8	8 1/8	5 3/4	3 3/4	6 5/8	8 1/8	5 3/4	2 7/8
4	3	7 1/16	8 23/32	6 1/8	4	7 1/16	8 23/32	6 1/8	3 1/16
4 1/4	2 7/8	7 1/2	9 5/16	6 1/2	4 1/4	7 1/2	9 5/16	6 1/2	3 1/4
4 1/2	2 3/4	7 15/16	9 29/32	6 7/8	4 1/2	7 15/16	9 29/32	6 7/8	3 7/16
4 3/4	2 5/8	8 3/8	10 1/2	7 1/4	4 3/4	8 3/8	10 1/2	7 1/4	3 5/8
5	2 1/2	8 13/16	10 15/16	7 5/8	5	8 13/16	10 15/16	7 5/8	3 13/16
5 1/4	2 1/2	9 1/4	11 5/16	8	5 1/4	9 1/4	11 5/16	8	4
5 1/2	2 3/8	9 11/16	11 27/32	8 3/8	5 1/2	9 11/16	11 27/32	8 3/8	4 1/16
5 3/4	2 3/8	10 5/32	12 3/8	8 3/4	5 3/4	10 5/32	12 3/8	8 3/4	4 1/8
6	2 1/4	10 17/32	12 29/32	9 1/8	6	10 17/32	12 29/32	9 1/8	4 5/16

The Whitworth system, which is extensively used in England, differs from the Sellers system chiefly in the form of the thread; this is of a V form, with the surfaces inclined to each other at an angle of 55° instead of 60°. The tops of the threads and the bottoms of the grooves are *rounded off* with arcs of equal radii, of such magnitude as to reduce the depth of the thread to two thirds that of the original V. The following formulæ give close approximations to the dimensions in the second table:

$P = 0.08D + 0.04$;

Number of threads per inch, ... $\frac{1}{P}$;

Diameter inside of thread, ... $0.9D - 0.05$;

Short diameter of head and nut, hexagonal or square, . . $1.5D + 0.18$;

Depth of nut, ... D.

WHITWORTH SYSTEM.

Diameter of Bolt.	Threads per Inch.	Short Diameter, Head and Nut.	Depth.		Diameter of Bolts.	Threads per Inch.	Short Diameter, Head and Nut.	Depth.	
			Nut.	Head.				Nut.	Head.
$\frac{1}{4}$	20	$\frac{33}{64}$	$\frac{1}{4}$	$\frac{7}{32}$	$1\frac{1}{8}$	6	$2\frac{7}{32}$	$1\frac{1}{8}$	$1\frac{13}{64}$
$\frac{5}{16}$	18	$\frac{41}{64}$	$\frac{5}{16}$	$\frac{17}{64}$	$1\frac{1}{4}$	6	$2\frac{13}{32}$	$1\frac{1}{4}$	$1\frac{5}{16}$
$\frac{3}{8}$	16	$\frac{49}{64}$	$\frac{3}{8}$	$\frac{21}{64}$	$1\frac{3}{8}$	5	$2\frac{37}{64}$	$1\frac{3}{8}$	$1\frac{37}{64}$
$\frac{7}{16}$	14	$\frac{57}{64}$	$\frac{7}{16}$	$\frac{3}{8}$	$1\frac{1}{2}$	5	$2\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{17}{32}$
$\frac{1}{2}$	12	$\frac{33}{32}$	$\frac{1}{2}$	$\frac{7}{16}$	$1\frac{7}{8}$	$4\frac{1}{2}$	$3\frac{1}{16}$	$1\frac{7}{8}$	$1\frac{41}{64}$
$\frac{5}{8}$	11	$1\frac{9}{32}$	$\frac{5}{8}$	$\frac{25}{64}$	2	$4\frac{1}{2}$	$3\frac{5}{32}$	2	$1\frac{3}{4}$
$\frac{3}{4}$	10	$1\frac{13}{32}$	$\frac{3}{4}$	$\frac{31}{64}$	$2\frac{1}{4}$	4	$3\frac{25}{64}$	$2\frac{1}{4}$	$1\frac{31}{32}$
$\frac{7}{8}$	9	$1\frac{31}{64}$	$\frac{7}{8}$	$\frac{43}{64}$	$2\frac{1}{2}$	4	$3\frac{57}{64}$	$2\frac{1}{2}$	$2\frac{3}{16}$
1	8	$1\frac{49}{64}$	1	$\frac{7}{8}$	$2\frac{3}{4}$	$3\frac{1}{2}$	$4\frac{3}{16}$	$2\frac{3}{4}$	$2\frac{13}{32}$
$1\frac{1}{8}$	7	$1\frac{65}{64}$	$1\frac{1}{8}$	$\frac{49}{64}$	3	$3\frac{1}{2}$	$4\frac{17}{32}$	3	$2\frac{3}{8}$
$1\frac{1}{4}$	7	$2\frac{1}{64}$	$1\frac{1}{4}$	$1\frac{3}{32}$					

The third table gives data relating to standard pipe-threads, in drawing which the following instructions are to be observed:

The tube is tapered on the outside as far as the perfect threads extend; back of those are two threads, perfect at the bottom but imperfect at the top: the bottoms of all these lie in a line parallel to the outside taper. Beyond these, agai'n, are four threads, imperfect at both top and bottom: the manner of drawing these is essentially arbitrary.

The angle of the thread is 60°, rounded off at top and bottom alike, so as to leave a depth of $\frac{4}{5}$ the pitch.

STANDARD DIMENSIONS OF WROUGHT-IRON WELDED TUBES.

Diameter of Tube.			Thickness of Metal.	Screwed Ends.	
Nominal Inside.	Actual Inside.	Actual Outside.		Number of Threads per Inch.	Length of Perfect Screw.
Inches.	Inches.	Inches.	Inch.	No.	Inch.
$\frac{1}{8}$	0.270	0.405	0.068	27	0.19
$\frac{1}{4}$	0.364	0.540	0.088	18	0.29
$\frac{3}{8}$	0.494	0.675	0.091	18	0.30
$\frac{1}{2}$	0.623	0.840	0.109	14	0.39
$\frac{3}{4}$	0.824	1.050	0.113	14	0.40
1	1.048	1.315	0.134	$11\frac{1}{2}$	0.51
$1\frac{1}{4}$	1.380	1.660	0.140	$11\frac{1}{2}$	0.54
$1\frac{1}{2}$	1.610	1.900	0.145	$11\frac{1}{2}$	0.55
2	2.067	2.375	0.154	$11\frac{1}{2}$	0.58
$2\frac{1}{2}$	2.468	2.875	0.204	8	0.89
3	3.067	3.500	0.217	8	0.95
$3\frac{1}{2}$	3.548	4.000	0.226	8	1.00
4	4.026	4.500	0.237	8	1.05
$4\frac{1}{2}$	4.508	5.000	0.246	8	1.10
5	5.045	5.563	0.259	8	1.16
6	6.065	6.625	0.280	8	1.26
7	7.023	7 625	0.301	8	1.36
8	7.982	8.625	0.322	8	1.46
9	9.000	9.688	0.344	8	1.57
10	10.019	10.750	0.366	8	1.68

Taper of conical tube-ends, 1 in 32 to axis of tube.

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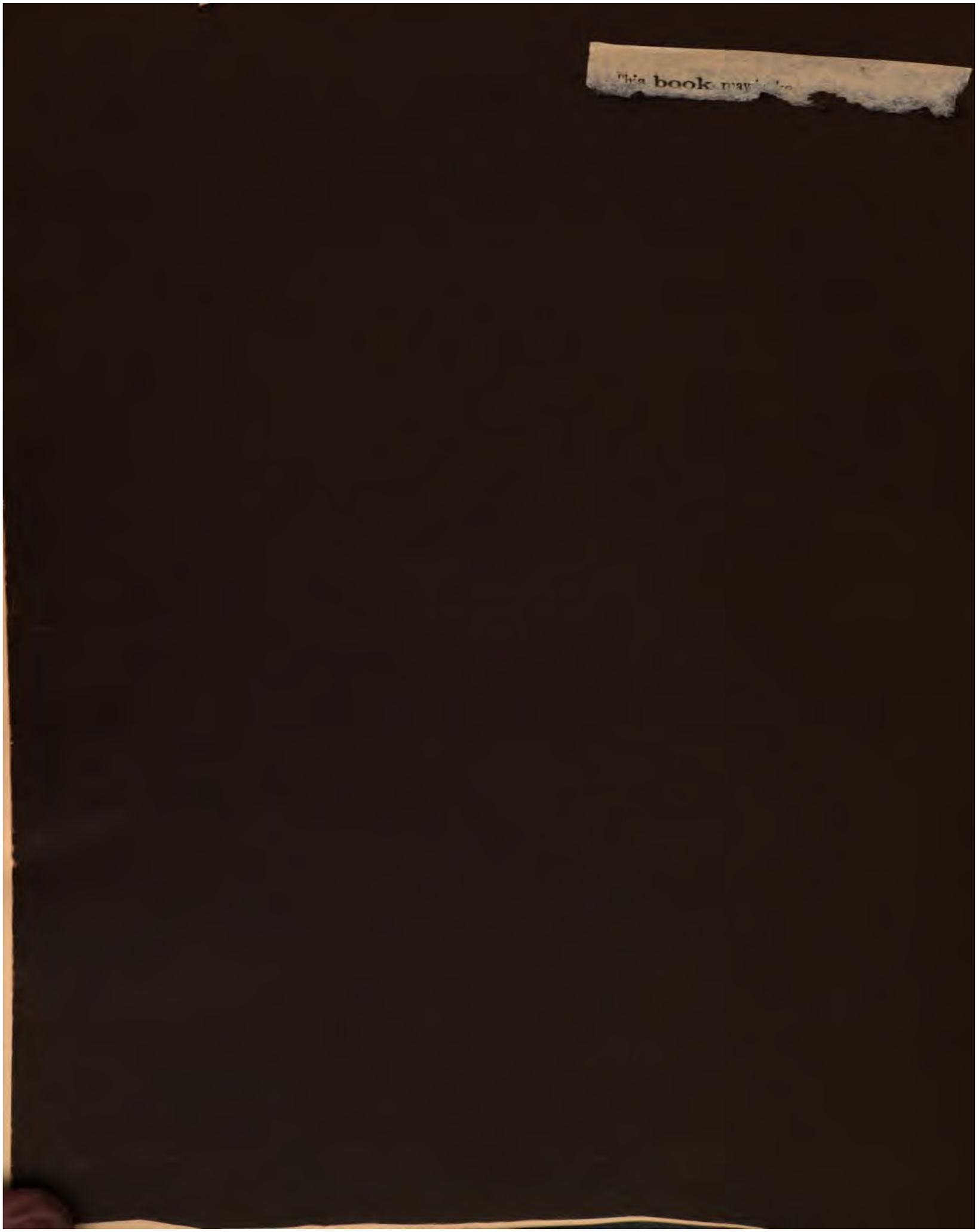
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